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The impact of actual and surrogate variegated cutworm stubble phytophagy on the growth and yield of alfalfa

G. David Buntin
Iowa State University

Buntin, G. David

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The impact of actual and surrogate variegated cutworm stubble phytophagy on the growth and yield of alfalfa

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G. David Buntin

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INTRODUCTION

The ultimate goal of most applied entomological research is the development of more effective technology and strategies of pest control. Typically, integrated pest management (IPM) strives to maintain pest populations below levels that cause economic loss through the optimal use of control tactics, while minimizing producer costs and adverse environmental effects (NAS 1969). IPM is a holistic approach that considers pest suppression in the context of the entire production system, rather than in isolation from other production factors. This approach requires an extensive knowledge of pest biology, plus an understanding of pest/plant interaction.

Implicit in the definition of IPM is the concept of economic damage and economic injury level (EIL), which integrate pest and plant biologies with economics. Although the idea of incorporating economics into the criteria of pest control decisions was being discussed as early as the 1930s (Pierce 1934), specific concepts were first clearly outlined by Stern et al. in 1959. They defined EIL as "the lowest population density that will cause economic damage," where economic damage is "the amount of injury which will justify the cost of artificial control measures." An additional concept, the economic threshold (ET), was defined as "the density at which control measures should be initiated to prevent an increasing pest population from reaching the EIL." The four elements needed for the calculation of an EIL are cost of control, commodity price, proportional injury per individual pest, and crop response to injury such as yield or quality reduction (Stone and Pedigo 1972). Con-

sequently, the EIL and ET concepts have been employed most extensively with insects in agricultural systems, because commodity prices and quality standards are readily available. The EIL concept has been less useful in nonagricultural situations, such as urban and medical pest control, because of aesthetic and social considerations and the difficulty of expressing losses in monetary terms.

The development of EILs is a dynamic process. EILs evolve through a series of stages and become more complete as knowledge of the crop, pests, and their interaction increases (Poston et al. 1983). This evolution has been categorized into the following four stages: (1) no EIL, (2) nominal EIL based on the best guess of workers in the field, (3) simple EIL based on quantitative research data for a single pest, and (4) comprehensive EIL that incorporates multiple pests and stress factors for a variety of growing environments and economic situations (Poston et al. 1983). Most current IPM programs rely upon nominal or simple EILs.

The development of valid and applicable EILs requires the elucidation of insect/plant interaction, particularly the crop response to insect injury. The traditional approach by entomologists to the study of crop stress has been to examine the effect of insect density on final productivity, measured as yield and/or quality. Although useful in the calculations of simple EILs, this "black-box" approach has ignored the mechanism of crop response to injury. The applicability of thresholds derived in this manner is limited, because of the inability to predict how a plant may respond in different environments and interact with other stresses. The construction of more comprehensive EILs will require a

more thorough and basic understanding of plant response to insect stress. The investigation of plant/pest relationships will be enhanced by a more holistic and agronomic approach to insect-induced plant stress.

This approach requires the quantification of the impact of insect injury on plant growth, development, and other processes such as photosynthesis and carbon flow within the plant. Furthermore, an understanding of how pests injure plants is needed. Boote (1981) has placed pests into a number of categories based on the type of damage inflicted on the crop. These categories are: stand reducers, leaf-mass consumers, leaf (photosynthesis) rate reducers, senescence enhancers, light stealers, assimilate sappers, turgor reducers, and fruit feeders that reduce both quantify and/or quality. Insects potentially can fall into any of the categories, except, perhaps, light stealers. One of the most common types of insect injury is defoliation. Insect defoliators primarily are leaf-mass consumers, and mainly affect the plant through the removal of leaf mass and area. The photosynthetic capacity of remaining individual leaves generally is reduced little. Canopy photosynthesis, however, can be reduced by the loss of leaf area and reduction of light interception.

The effect of defoliation by insects on subsequent growth rates and dry matter partitioning by plants has not been studied extensively. It is possible that plants may compensate for defoliation by the production of additional leaf mass and area. Boote (1981), however, claims that, at least in annual seed-producing crops, compensatory growth is a myth. At best, leaf growth is no more than normal for a undamaged canopy, thus the loss in leaf mass is permanent and will remain until senescence. Recent studies with soybean (Higgins et al. 1983, Hinson et al. 1978) and

alfalfa (Fick 1982) support this conclusion. Defoliation in these studies, however, occurred at the beginning of flowering, consequently the injury may have occurred too late for the plant to produce compensatory growth. Compensatory growth may occur if damage is inflicted at an early stage of plant development.

This dissertation documents the study of these concepts in a system involving the variegated cutworm (VCW), Peridroma saucia (Hübner), in alfalfa. Although VCW attacks over 120 plant species (Rings et al. 1976b), the species is of concern as a pest of alfalfa because it causes delays in regrowth for up to two weeks or more (Soteres et al. 1984, USDA 1957-1975). Damage usually is noticed only when regrowth is delayed completely, with less severe defoliation largely going unnoticed. Current management practices recommend the curative application of an insecticide once damage is detected. The nominal ET of 1.1 larvae/ 0.1 m^2 (1 larva/ft^2) has been proposed (DeWitt and Taylor 1984), but this value is based on limited research data. Systematic examination of the effects of stubble injury on alfalfa regrowth is needed to develop simple EILs for VCW in alfalfa. This examination also will provide a foundation for the development of more comprehensive and dynamic EILs for other stubble defoliators in alfalfa.

The research, therefore, investigates the response of alfalfa regrowth to actual and simulated injury by VCW. Specific objectives of the study were to:

1) Characterize the alfalfa response-syndrome to stubble injury in terms of dry matter production, plant development, and resource partitioning;

2) Assess the impact of complete regrowth delays of varying periods on subsequent alfalfa growth and yield;
3) Elucidate the relationship between the density of stubble-feeding VCW and alfalfa growth and yield;
4) Quantify VCW growth and consumption on alfalfa foliage;
5) Develop valid and dynamic EILs and develop management practices for this insect in alfalfa; and
6) Make progress toward the development of comprehensive EILs for stubble-feeding insects in alfalfa.

LITERATURE REVIEW

The review of literature is divided into two parts. The first part reviews the biology and damage potential of the variegated cutworm. The second part summarizes information on alfalfa with emphasis on relevant studies on the effects of defoliation on alfalfa growth and development.

Variegated Cutworm Biology

Life history and ecology

The variegated cutworm (VCW), Peridroma saucia (Hübner), has been found from southern Canada to Patagonia and from Scandinavia throughout Europe to northern Africa and the Middle East (Snyder 1951). Since its description by Hübner, many studies and reports on VCW have been published (see Rings et al. (1976a) for a complete bibliography). Our knowledge of the VCW biology is based primarily on the works of Chittenden (1901), Crumb (1929), Doane and Brodie (1901), Wadley (1921), and Walkden (1950). Crumb (1929) also gave detailed descriptions of each life stage. Unless indicated otherwise, the discussion of VCW biology will be based on these references.

Eggs are laid in masses of 30-300 eggs/mass (Wadley 1921), and initially they are cream color. As development proceeds, the eggs become reddish brown and immediately before hatching they appear dark gray. Egg development requires 7 to 10 days, and larvae disperse and initiate feeding soon after hatching. VCW seems rather indiscriminant during oviposition. Eggs usually are laid on vegetation or debris near the food plant;

however, eggs have been observed on buildings, fence posts, and other nonfood substrates.

VCW larvae generally undergo six larval instars. The first three larval stages usually occur on the aerial portions of the host plant, where feeding is primarily a diurnal activity. As larvae become older, they exhibit the more typical behavior of a climbing cutworm. During the day, larvae are inactive and hide under debris on the soil surface. At night, larvae become active and climb foliage to feed. This negatively phototactic behavior becomes more pronounced with each succeeding stage, but the greatest behavioral transition occurs during the third and fourth stadia. If food becomes scarce, large larvae will exhibit armyworm-like behavior by moving, en masse, to adjacent fields.

VCW is highly polyphagous and is reported to feed on at least 121 host plants (Rings et al. 1976a). The list includes many vegetable, orchard, ornamental, and field crop species along with a number of noncrop and weed species. Although quite a few species of grasses are reported as hosts, VCW shows a distinct preference for broadleaved species, especially legumes (Snyder 1954).

Regardless of the host plant, VCW can consume a large amount of foliage. Stages 4-6 have been found to consume a total of 130.85 cm^2 of sugarbeet foliage (Capinera 1978) and a total of 158 cm^2 of potato foliage (Shields 1983). Berry and Shields (1980) also reported that a total of 174.4 cm^2 of peppermint leaves was consumed by stages 3 through 6. This total was the equivalent of 26 average-sized peppermint leaves, and over 94% of these leaves were consumed by the last two stages. It is apparent that there are substantial differences in consumptive rates on

different hosts. Some of these differences probably are caused by differences in the leaf weight-to-area ratios of the host plants. Host-leaf nutritional values also may explain some of the differences in consumption rates.

Diet also may affect the number of larval molts and larval developmental rates. Snyder (1954) found that less than 10% of larvae fed kale, bean leaf, string bean, spinach, tobacco, and cabbage underwent a seventh stage. Alfalfa caused 11% of larvae to have an extra molt. Celery, tomato, lettuce, and corn leaf, however, resulted in 29, 67, 93, and 100% of larvae, respectively, to undergo a seventh stage. Furthermore, an eighth stage was observed in half of the larvae fed lettuce, and corn leaf caused 100, 56, and 11% of larvae to undergo an eighth, ninth, and tenth stage, respectively.

The influence of diet on larval developmental rates can be substantial. Snyder (1954) reported that larval stadia at 25°C ranged from 22.2 days on kale to 44.0 days on corn with a mean of 30.9 days for all twelve hosts. Development on alfalfa required 26.9 days. Tomescu et al. (1978) found that larval development on an unspecified artificial diet took 30 days at 24°C and 60% RH. Additionally, VCW larval stages 2-6 required 27.5 days to complete development at 27°C on sugarbeet foliage (Capinera 1978), and stages 3-6 required 21.9 days at 25°C when fed peppermint foliage (Berry and Shields 1980). From these results, it seems VCW larval development requires about 30 days at ca. 25°C for most diets. The work of Snyder (1954), however, suggests that some hosts are less suitable than others, and VCW may exhibit substrate specific rates of development.

The other primary environmental factor determining larval development is temperature. Two thermal developmental models have been developed for VCW (Simonet et al. 1981, Shields 1983). Larvae were reared on artificial diets in both studies, but Simonet et al. used a pinto bean-based diet, whereas Shields substituted lima beans for pinto beans. Simonet et al. calculated theoretical lower developmental thresholds for egg, larval, pupal, and total development to be 5.6, 6.7, 8.5, and 7.1°C, respectively. Shields calculated these same values as 3.0, 4.1, 5.0, and 4.2°C, respectively. The model of Simonet et al. required 676°C degree days for total development, and Shield's model required 798°C degree days. Shield attributed model differences to the observed development times at 10°C in both studies. This time was 126 days in the Simonet et al. study and 64 days in Shield's study. The differences between these studies may be caused by the length of time that the insect was reared in the laboratory before experimentation. Furthermore, the differences in diet may be partly responsible for the observed differences in developmental rates (Shield 1983).

Larval consumption declines substantially four to six days before pupation (Capinera 1978). When the larva is full grown and finished feeding, it burrows into the soil and forms a pupation chamber. Once in place, the larva undergoes a one to two day prepupal phase before pupation when larval wet weight may decline by 50% or more (Capinera 1978). Most of this weight loss occurs by elimination of water. Pupation takes place inside the pupation chamber. The pupal stadium has been reported to last 13-14 days at 24°C (Tomescu et al. 1978) and 15-17 days at 25°C (Snyder 1954). Snyder found that the pupal stadium was not greatly

affected by larval diet. Weight of 1-day old pupae, however, was greatly affected by larval diet. Weights ranged from 480 mg on string bean to 231 mg on corn leaf. Pupal survivorship was not consistently correlated with pupal weight. Upon emergence, the adult makes its way to the soil surface.

The adult is a fairly large moth that can be identified by the kidney-shaped reniform and the sets of paired spots along the costal edge of the forewing. Although adults do not exhibit sexual dimorphism, three adult color morphs have been identified, based on the basal color of the forewing. The typical morph has a tan to light brown-colored forewing. Forewing color in form "margaritosa" is reddish to purplish brown, and the forewing of "semifusca" is tan, like the typical form, but the costal area is black. The regulatory mechanism of adult polymorphism is unknown. The ecological significance of adult polymorphism also is unclear, but Wadley (1921) speculated that form "margaritosa" may exhibit an ovarian diapause.

Adult longevity is variable. Wadley (1921) reported that adults live for 8 to 13 days and Tomescu et al. (1978) reported 10 to 20 days. Simonet et al. (1981), however, found that adult longevity was temperature dependent, with adults living up to 24 days at 12.8°C. These authors also found that VCW exhibited a preovipositional period ranging from 5.5 days at 29.4°C to 13.9 days at 12.8°C. This range is similar to the 6 to 8 days reported by Crumb (1929), but longer than the 3-day preovipositional period reported by Wadley (1921). Females normally begin mating at this time and may mate a number of times during their adult life.

Each female is capable of laying several thousand eggs. Walkden (1950) calculated an average of 2111 eggs/female and Cook (1923) reported a mean of 1497 eggs/female. Simonet et al. (1981), however, found that fecundity is temperature dependent. Peak egg production of 1415 eggs/female occurred at 23.9°C. Egg production was 377, 1161, and 424 eggs/female at 12.8, 18.3, and 29.4°C, respectively. The influence of larval diet on fecundity has not been investigated.

Detailed studies of the mating and ovipositional behavior of VCW have not been conducted. Even so, mating is mediated by sex pheromones, and Strubles et al. (1976) found that a 1:1 mixture of Z-9-tetradecen-1-yl acetate and Z-11-hexadecen-1-yl acetate is effective in attracting males. VCW males also possess scent brushes located on the dorsal portion of the anterior abdominal segments. These structures have been postulated to secrete compounds that inhibit calling behavior in the female (Birch et al. 1976). It is apparent that the chemical communication system in VCW may be quite complex.

The number of generations and mode of overwintering by VCW are subjects that have received much speculation but little thorough study. Table 1 summarizes the number of generations and probable overwintering stages that are reported in the literature. Generally, two generations per year are reported for the northern US and Canada, and three to four generations are reported in southern areas of the US. Based on the information in Table 1, VCW probably has two generations per year in Iowa.

All stages, except the egg stage, have been suggested as the overwintering stage. Snyder (1951) clearly demonstrated that the egg stage cannot withstand extended periods of temperatures near or below freezing.

Table 1. Number of flights and generations, and overwintering stages of the variegated cutworm reported in the literature

Location	Number of gen.	Number of flights	Stage[a]	References
Arkansas	2	3	-	Selman and Barton (1972)
Tennessee	4	4	P&L	Crumb (1929)
Kansas	3	3-4	A	Wadley (1921)
Kansas	3-4	3-4	P	Walkden (1950)
Kentucky	-	-	A (in part)	Garman (1895)
District of Columbia	2	2	L&?P	Chittenden (1901)
Ohio	2	2	L&P	Simonet et al. (1981)
Illinois	2	-	L,P&A	Forbes (1904)
Pennsylvania	2	-	L(3-5)&P	Frost (1955)
Maine	2	2-3	-	Dirks (1937)
Minnesota	2	2	L(med.),P&?A	Knutson (1944)
Washington	1-2	3	L,P&A	Doane and Brodie (1901)
Ontario	-	-	migration	McClanahan and Elliott (1976)
Manitoba	2	2	migration	Ayre et al. (1983)
Canada	2	2	-	Gibson (1915)

[a]L = larvae, P = pupae, A = adult, and ? = possible overwintering stage.

The most often mentioned overwintering stages are partly-grown larvae (instars 3 to 6) and pupae. Both stages have been collected during the winter by some of the researchers. Chittenden (1901) stated that larvae may be active on warm days during the winter and that pupation takes place as soon as the ground warms in the spring. Crumb (1929), on the other hand, felt that VCW overwintered mostly as pupae, with larvae overwintering to a lesser extent. Some authors also have suggested that the adult stage may overwinter, and Chittenden (1901) speculated that VCW has continuous generations in the southern-most portions of the US. Crumb (1929), however, felt that VCW does not overwinter as an adult. If VCW can overwinter as an adult, this mode of overwintering probably is restricted to the milder portions of the insect's range.

Despite all the field observations of overwintering larvae and pupae, Ayre et al. (1983) reported that no stage can tolerate extended periods of freezing temperatures in the laboratory. No details of the experimental procedures were provided however. These authors, McClanahan and Elliot (1976) and researchers in Europe have hypothesized that VCW does not overwinter in the northern part of its range. Populations in these areas are initiated each spring by migration of adults from southern overwintering areas. It is possible that in some areas both indigenous overwintering cohorts and migrating adults are important sources of initial spring populations.

Unfortunately, no studies have specifically investigated the overwintering, migration, and diapause potential of VCW. Diapause has not been clearly demonstrated to occur in VCW. If diapause exists in this insect, undoubtedly it is facultative. In fact, Finney (1964) felt that

VCW was a good animal for laboratory studies because the life cycle was not interrupted by diapause. Snyder (1951) was unable to induce larval or pupal diapause under any of the temperature or light regimes he tested. Until the overwintering and diapause potential of VCW is investigated more thoroughly, many of the basic questions concerning VCW biology will remain unresolved.

Economic importance

The wide host range and sudden periodic outbreaks of VCW make this species potentially one of the most destructive cutworms in North America (Crumb 1929, Doane and Brodie 1901, Wadley 1921). When an outbreak occurs, VCW usually infests most suitable hosts in the area. The most commonly damaged crops are alfalfa, cabbage, clovers, cotton, lettuce, potatoes, tobacco, and tomato (Snyder 1951). VCW also seems to cause considerable damage in peppermint (Berry and Shields 1980). Additionally, VCW often is a pest for home owners, because it will infest gardens and damage ornamentals. During heavy infestations, VCW has even been reported to feed on potato tubers (Chittenden 1901). The greatest economic impact probably is in vegetable crops, of which potato and tomato are most frequently damaged (Rings et al. 1976b). This is primarily because vegetables are high cash-value crops that can withstand little damage before economic loss occurs. Furthermore, VCW may feed directly on developing flowers, buds, and fruit, thus causing direct loss to the harvestable product and reduction in product quality.

Few people have attempted to assess the losses caused by VCW, but Chittenden (1902) estimated that losses during the "great" outbreak of

1900 were $2.5 million. This outbreak was so severe and widespread in North America that larvae destroyed entire fields of crops and moved en masse from field to field. Doane and Brodie (1901) stated that "they (the larvae) would carry everything before them, for they had by this time (July 15) literally become an invading army, marching on from garden to garden, from field to field, from orchard to orchard, eating every green plant that came in their path."

In Iowa and the Great Plains, VCW is of most concern as a pest of alfalfa. Potatoes also are sometimes damaged in the upper Midwest. Examination of the Cooperative Economic Insect Report from 1957 to 1975 and the Cooperative Plant Pest Report from 1976 to 1981 indicates that VCW primarily is a pest in alfalfa in the area from the Mississippi River west to the Rocky Mountains. Alfalfa-growing areas in California, Nevada, and Utah also reported damaging populations. VCW was not often reported damaging alfalfa in the humid east. The regional nature of the VCW problem in alfalfa is exemplified by the fact that VCW is considered an important pest of alfalfa in Kansas (Grandfield and Throckmorton 1945), but it is considered only a minor pest of alfalfa in Delaware (Milliron 1958).

Based on the number of reports from 1957 through 1981, outbreaks occurred 12 of the 24 years examined. Furthermore, outbreaks generally occurred every two to three years and, except for one case, they occurred every other year from 1968 through 1981. It was uncommon for outbreaks to happen during two consecutive years. This suggests that in the Great Plains, VCW may exhibit population cycles of two to three years in duration.

Physiology of Alfalfa Regrowth

Role of carbohydrates in regrowth

The association between the cutting of alfalfa and the cyclic changes in root weight, and accumulated carbohydrates in the roots and to a lesser extent in the crown, has been demonstrated by many studies (Grueb and Wedin 1971, Nelson and Smith 1968a, Smith 1972, Smith and Nelson 1967). Graber et al. (1927) were the first to suggest that nonstructural carbohydrates that accumulated in the crowns and taproots were an important source of nutrition for regrowth in alfalfa. Many researchers have concurred with this hypothesis; however, some studies (Hodgkinson 1973 and 1974) have stressed the importance of current photosynthesis (Ps) by stubble leaves as a source of carbohydrates for regrowth.

Carbohydrates in alfalfa are stored primarily as starch, but significant amounts of sucrose, glucose, and fructose also are present in the plant (Nelson and Smith 1968b). Most of the cycling of carbohydrates occurs with the starch fraction (Nelson and Smith 1968b), and sucrose probably is the primary transport carbohydrate within the plant (Brown et al. 1972).

The carbohydrate cycle consists of a rapid decline in stored carbohydrates after cutting until about 15 to 20 days postcutting. Carbohydrate levels in the roots begin to increase about three to four weeks after cutting and usually reach maximal levels about full bloom. The extent of depletion and time needed for replenishing the reserves will depend on many factors, including the frequency and intensity of cutting, stage of maturity at cutting, the climate (humid vs. xeric), and the

external environmental conditions during regrowth (Bolton 1962, Smith 1975).

Smith and Silva (1969) indirectly examined the contribution of root reserves to regrowth by comparing the regrowth of plants under light and dark conditions. No significant differences in the levels of root carbohydrates were found during the first 21 days of regrowth, indicating that reserve utilization was similar in both environments. Most of the reserves (66%) were translocated and used by the herbage. Herbage weights, however, were significantly different on and after day 14, suggesting that current Ps contributed significantly to top regrowth after the first week. The contribution of current Ps to total plant weight was calculated by subtraction to be 0, 52, 70, and 93% of total plant weight on days 7, 14, 21, and 42 after cutting, respectively.

Smith and Silva also observed small but significant declines in root nitrogen (N) during the period of carbohydrate depletion suggesting that stored nitrogenous compounds also may be translocated to new shoots. These compounds, however, probably are not being used primarily as a source of N because Hodgkinson (1973) showed that N demand was met by current root uptake and not by remobilization of stored N. N compounds, therefore, may be translocated and used as an energy source during regrowth.

The role of accumulated carbohydrates in regrowth was not clearly demonstrated until ca. 1969 with the use of radiactive carbon (^{14}C) (Hodgkinson 1969, Pearce et al. 1969, Smith and Marten 1970). Pearce et al. studied the flow of carbon by adding ^{14}C to plants weekly during a regrowth cycle. The location and loss of ^{14}C was monitored during

this cycle and during the subsequent regrowth cycle, when no additional ^{14}C was added. This study clearly demonstrated the movement of ^{14}C from tops into roots before cutting and a reverse movement of carbon from the roots to new shoots after cutting. The depletion of carbohydrates in the roots after cutting showed a sigmoid rate of decline, with maximal rate of starch breakdown occurring between days 3 to 15. At the same time, levels of ^{14}C increased in tops until day 15. Root carbohydrate levels remained low from day 15 to 28, and it was not until day 21 that the net flow of carbon was from tops to roots. As top growth accumulated, the net flow of ^{14}C to the roots increased after day 21, so that ca. 36% of the ^{14}C added on day 35 was translocated to the roots and converted into starch. Starch breakdown, therefore, occurred from day 3 to 15 and starch synthesis began on day 21 and continued until the next cutting.

During the first three days after cutting, the free sugar fraction (ETOH extractable) declined significantly, but there was not significant decline in stored starch until the sixth day. Indicative of the three-day lag in starch breakdown was the observation that the percentage of ^{14}C in the roots declined only 4% from day 0 to 3 but declined by 9% from day 3 to 6. Additionally, the acid nonextractable ^{14}C fraction in the crowns increased substantially during the first three days of regrowth. All carbohydrate fractions in the roots and crowns declined after the third day. Vance et al. (1979) also found that root starch breakdown did not begin until the fourth day of regrowth. Pearce et al. interpreted these results as indicating that the plant was switching from starch synthesis to starch degradation during the first three days of plant regrowth. The free sugar fraction was used to produce the

proteins needed for the mobilization and utilization of the stored carbohydrates, and the increase in acid nonextractable ^{14}C in the crown was associated with the production of proteins required for regrowth.

The ^{14}C studies of Hodgkinson (1969) and Smith and Marten (1970) essentially showed the same results as those of Pearce et al. Both of these studies, however, indicated that most of the ^{14}C translocated from the roots to the tops was used for respiration and not for the synthesis of structural material. Hodgkinson further discovered that translocated carbon was used by the first few leaves produced, but leaves generally were self-sufficient and actually exported photosynthates after the sixth day of regrowth. Stems, however, continued to import and used carbohydrates translocated from the roots during the first 20 days of regrowth. Therefore, the Ps capabilities of leaves seem to be established after about one week of regrowth, whereas stems continue to utilize stored carbohydrates for about three weeks.

While it is clear that accumulated carbohydrates are an important and, usually, primary source of nutrition during the initial stages of regrowth, current Ps by leaves remaining on the stubble after cutting also máy be an important source of nutrition for regrowth. The Ps capabilities of stubble leaves have been specifically investigated in a number of studies (Hodgkinson 1973 and 1974, Hodgkinson et al. 1972). The Ps capacity and potential for rejuvenation of stubble leaves will depend on leaf age and the light environment to which the leaf was exposed. The Ps capacity of leaves declines greatly after about three weeks of age (Fuess and Tesar 1968). Cutting of alfalfa, however, has been found to rejuvenate stubble leaf Ps with net CO_2 exchange rates

rising from 55 to 130 ng $CO_2/cm^2/sec$ (Hodgkinson et al. 1972). Partial defoliation was found to cause a complete rejuvenation in young and middle-aged leaves, but only a partial recovery in older leaves (Hodgkinson 1974). The rejuvenation of stubble leaves by cutting probably was caused by the increase in light and nutrients available to the leaves after cutting.

Hodgkinson et al. (1972) found that retention of stubble leaves reduced the loss of root weight and depletion of root carbohydrate levels, but there was no significant increase in the rate of shoot growth. These results suggest that current Ps will be used preferentially during regrowth, if it is available. These authors felt that the role of carbohydrate reserves is passive rather than active in that reserve carbohydrates will be used, if necessary, to supplement the needs of the plant. If current photosynthates are not available and reserves are adequate, reserves alone are sufficient for maximal rate of regrowth.

From these results, Hodgkinson et al. (1972) concluded that the retention of stubble leaves was beneficial and should be encouraged especially if the frequency of cutting does not allow enough time to replenish carbohydrate reserves. The studies of Hodgkinson and his associates, however, were all conducted in the greenhouse where shading of lower leaves probably was not as great as compared with a field situation. These studies also were conducted with plants less than one year old, which probably would result in plants having reduced root storage capacity as compared with field plants. Furthermore, plants were cut in pre-flowering stages presumably before reserves could be entirely replenished and stubble leaves degenerated. In a field situation,

usually by the time harvest occurs most stubble leaves are four to five weeks old. These leaves have been shaded for two to three weeks and probably have abscissed or degenerated beyond the "point-of-no-return" because of natural processes and leaf diseases (Fuess and Tesar 1968). Fuess and Tesar found that even if stubble leaves were still present at harvest, 21-day-old leaves had 1/7 the Ps rate of young leaves. Brown et al. (1972) also found that net CO_2 exchange rates of stubble leaves in the field were low and suggested that stubble leaves may be a detriment rather than a benefit. Considering all these factors, the studies of Hodgkinson and his associates probably have overstated the relative importance of the retention of stubble leaves in most field situations.

Development of canopy structure

Canopy growth and development is a dynamic process that is affected by the unique innate qualities of the plant and the environment in which the plant occurs. In general, there are three phases of canopy development; phase of bud and shoot initiation, vegetative growth phase, and reproductive growth phase. The period of bud initiation is when potential stem density is determined, whereas the periods of vegetative and reproductive growth determine shoot size, shoot quality, and final stem density. The yield of alfalfa is determined primarily by the two components of stem density and stem weight. Plant density generally is not correlated with yield as long as the number of plants/unit area is sufficient to provide a full stand of stems. A full stand has been

estimated as 375 stems/m^2 (Bula and Hintz 1978). This lack of correlation in a full stand is because the number of stems per plant varies inversely with plant density. To a certain extent this compensatory ability is a feature of most forage crops.

Shoots of alfalfa usually initiate at the nodes on stubble of the previous cutting (Leach 1968, Nelson and Smith 1968a, Singh and Winch 1974). A small portion of shoots also may arise directly from the crown. Furthermore, Hodgkinson (1973) demonstrated that most shoots arise at or near the base of the stubble. He found that almost 3/4 of the new shoots on plants cut at 15 cm arose within the basal 2.5 cm of the plant. This probably is why increased cutting height has not been found to greatly increase stem density (Smith 1972). Removal of residual stubble leaves also has been shown not to affect the number of new shoots (Leach 1968).

Leach (1968, 1969, and 1970) conducted a series of detailed studies on the regrowth of alfalfa in Australia. He studied the number and rate of bud initiation in plants subjected to cutting at various stages of maturity and at various intensities of cutting. Less severe cuttings increased shoot number, and later cutting increased both shoot number and size. Variation in cutting height, other than complete removal of stubble, did not affect shoot size.

Leach found that most of the observed treatment effects on yield and regrowth could be explained by variation in the number of shoots that regrew and the temporal pattern of shoot initiation. The rate of bud initiation in healthy plants was rapid, with most shoots beginning growth within seven days of cutting. Shoots beginning growth within the first week of regrowth contributed about 80% of the final yield at harvest.

Shoots beginning growth after the first week were few in number, had slower growth rates, and rarely continued to grow until harvest. Cutting plants at an earlier stage or completely removing all stubble reduced both the number of new shoots and the rate at which shoots initiated growth. Shoot initiation was gradual and occurred over a longer period of time than in healthy plants. Consequently, the crop growth rate (dry weight per unit area per day) was reduced. The growth rate of individual stems, however, was not affected by stage or intensity of cutting. Leach concluded that the rate of shoot initiation is equally as important as the number of initiated shoots. Therefore, management practices should attempt to maximize the number of shoots that initiate growth soon after cutting. Additionally, because shoot growth was unaffected by residual leaves, management practices should promote the rapid development of new leaf area, rather than the retention of old leaf area.

Hodgkinson (1973) also examined the effect of cutting height on alfalfa regrowth and nutrient uptake. As in Leach's studies, Hodgkinson found that nearly all new shoots initiated growth within seven days of cutting and most initiated growth within 3 to 5 days. Usually, half the new shoots, however, did not grow taller than 2.5 cm. He attributed this phenomenon to apical dominance which limited or stopped growth and nutrient uptake by uninitiated buds and subordinate shoots. Hodgkinson also found that most of the effects of cutting height developed during the first week of regrowth and persisted until harvest. Reduced regrowth during the first week probably was caused by a reduction in the rate of shoot initiation.

Cowett and Sprague (1962 and 1963) investigated the effects of various environmental and cultural factors on tillering. Tillering was reduced by inadequate soil moisture, low light intensity, high temperatures particularly at night, poor nutrient balance, and frequent cutting. All these conditions tended to reduce root weight and the accumulation of stored carbohydrates presumably by inhibiting Ps, increasing respiratory losses, or by not allowing enough time for the accumulation of carbohydrates. Most of the factors seem to directly or indirectly affect the carbohydrate accumulation and levels within the plant. Consequently, these authors concluded that carbohydrate levels probably are the most important factor governing tillering in alfalfa. This conclusion is consistent with the results of the studies by Leach and Hodgkinson.

As previously discussed, vegetative growth during the first 7 to 10 days is determined primarily by the levels of carbohydrate reserves. Although new leaves will begin to export photosynthate after the sixth day (Hodgkinson 1973), current Ps is not an important source of carbohdyrates during early shoot growth, unless stored carbohydrate levels are low (Leach 1968, Smith and Silva 1969). Current Ps quickly becomes important after about the tenth day, even though stems, but not leaves, will continue to use stored reserves for about 20 days (Hodgkinson 1969).

Once the period of bud initiation is complete, alfalfa exhibits a period of rapid vegetative growth. Stem density usually reaches a peak one to two weeks after cutting. Thereafter, stem density declines until harvest, with stem mortality sometimes exceeding 50% (Singh and Winch 1974). Nelson and Smith (1968a) found that most stems were unbranched during the first few weeks of growth. Axillary branches began develop-

ing in the axils of lower main-stem leaves and branching became extensive, especially in aftermath growths, as the plant continued to grow and entered the reproductive phase.

Alfalfa growth and canopy development has been studied under 2-, 3-, and 4-cut systems in the upper midwestern US by Fuess and Tesar (1968), Grueb and Wedin (1971), Nelson and Smith (1968b), Smith and Nelson (1967), and Wilfong et al. (1967). Growth and leaf area accumulations were low during the period of bud initiation (first 7 to 10 days). After this time, leaf area index (LAI) and dry matter accumulation increased in a rapid and almost linear pattern until flowering. LAI and yield were the largest during the spring growth in all the studies. LAI in the spring growth achieved 95% light interception about three weeks before flowering. Apparent canopy Ps (APs) and consequently crop growth rate (CGR) increased with LAI until 95% light interception. At this point, APs and CGR stopped increasing and remained constant until flowering, even though LAI continued to increase. Nelson and Smith (1968a) found that 95% light interception occurred at an LAI of 3.5 during the spring growth. After this point, LAI was optimal, because CGR had reached a maximal level. CGR usually remained high until flowering, and consequently, LAI was optimal over a broad range of LAI values in the spring. CGR and the rate of increase in LAI declined at flowering because of a reduction in vegetative growth and an increase in leaf senescence and abscission. Fuess and Tesar (1968) found that leaf droppage for plants harvested near full bloom was 1.19 MT/ha more than leaf droppage of plants harvested near 1/10 bloom.

Alfalfa regrowth during the summer generally progresses in a similar pattern as in the spring, but peak LAI and dry matter accumulation values are lower than in the spring. LAI increases rapidly after the bud initiation phase, but flowering, which is hastened by high summer temperatures (Nelson and Smith 1969), usually occurs before or near the point of 95% light interception. CGR also continues to increase until LAI reaches a peak at or near flowering. LAI, therefore, is optimal for only a short period of time before flowering and leaf abscission occur.

As alfalfa matures and enters the reproductive phase, LAI stops increasing, and racemes of flowers develop at the upper most nodes. Additional flower racemes also begin developing on upper main-stem and branch nodes. Concurrent with flowering, the Ps capacity of lower main-stem leaves declines, and senescence and droppage of these leaves increases. This has a large impact on LAI, because these leaves tend to be larger than the newer leaves on axillary branches. Stems also become woody and lignified with maturity. These trends combine to substantially reduce forage digestibility and nutritive value during flowering. The reduction in CGR and forage quality is the reason why systems that cut herbage near the beginning of flowering (first bloom or 1/10 bloom) are recommended for maximizing the production of digestible dry matter yield (Fuess and Tesar 1968, Grueb and Wedin 1971, Nelson and Smith 1968a, Smith 1975).

The reproductive phase also results in reduced apical dominance of crown and stubble buds (Hodgkinson 1973). These buds will develop and begin growth at about full bloom even if the herbage is not cut (Smith 1975). Buds generally are not fully developed until flowering and

usually are slow at initiating regrowth if the herbage is cut before flowering. Therefore, rapid bud initiation and growth usually occur when alfalfa is harvested after flowering has begun.

Response of Alfalfa Regrowth to Insect Injury

VCW causes direct injury to the harvestable product of alfalfa by feeding on leaves, small stems, and new shoots. VCW most often causes noticeable damage in alfalfa by feeding on new shoots soon after harvest. If a sufficient number of larvae are present, this type of damage may cause a complete delay in green-up for two weeks or more (Grandfield and Throckmorton 1945). Delays in green-up usually occur after the first cutting, but delays after later cuttings also have been reported (USDA 1976-1981). Most likely, some population densities do not cause complete delays in regrowth. Little quantitative data, however, is available on the impact of VCW feeding on alfalfa regrowth and yield. In Iowa, a nominal economic threshold of 1 larva/ft^2 has been used for newly cut alfalfa fields (DeWitt and Taylor 1984). This threshold is based mostly on experience rather than on experimental data.

VCW larvae also damages alfalfa between cuttings by feeding on leaves and lateral branches located in the lower and middle parts of the plant canopy. The impact of this type of damage is unknown. Nevertheless, leaf feeding probably would have a greater impact than would be expected based on yield loss alone. This is because ca. 2/3 of the digestible nutrients of alfalfa are located in the leaves (Smith 1975). Leaf feeding, therefore, would tend to reduce herbage quality to a

greater extent than yield. On the other hand, because leaf feeding occurs in the lower parts of the canopy, a large portion of the leaves damaged by larvae probably would have senesced and dropped from the plant before harvest. This last factor tends to reduce the impact of larval feeding between cuttings and probably is why damage to standing alfalfa generally is not reported. Consequently, VCW probably damages alfalfa mostly as a result of stubble feeding.

The impact of stubble feeding by insects has received little attention, and no studies have specifically assessed the effects of damage caused by VCW. Some studies, however, have investigated the effects of stubble feeding by other insects. Lui and Fick (1975) and Fick and Liu (1976) examined the season-long effects of alfalfa weevil (AW), Hypera postica (Gyllenhal), damage on the yield, quality, root reserves, developmental rate, and canopy structure of alfalfa. The studies were conducted on var. 'Saranac' and 'Iroquois' alfalfa under systems of two and three cuttings in New York state. Yield was significantly reduced by AW feeding only during the second growth of the 3-cut system. The first cutting of this system occurred before most larvae had pupated, thus, most larvae continued to feed during the first part of the second growth. This feeding caused delays of five to 15 days in regrowth. Damage was sufficient in one year to cause a 31% reduction in yield during the second growth and a 17% reduction in total seasonal yield. Effects on stem height and herbage quality, as measured by digestible dry matter and crude protein, were small and not significant. Stubble damage did cause a significant delay in morphological development, resulting in a difference in the chronological age of the herbage in

damaged and undamaged plots. These developmental differences, however, ameliorated before the end of second growth. Stubble feeding had no significant effect on root carbohydrate depletion, but the rate of carbohydrate replenishment was not as fast in damaged plants. Consequently, carbohydrate levels were significantly lower in damaged plants just before harvest. Nevertheless, regrowth during subsequent cycles was not reduced by AW feeding.

As a result of these studies, Fick (1976) specifically investigated the impact of AW stubble feeding on alfalfa regrowth. The study was conducted by infesting small plots with larvae up to densities of 10,260 larvae/m^2. Plots were infested on the fourth day after the first cutting. Larval feeding occurred until day 9, with larger larval populations causing longer delays. Yield losses were proportional to the severity and duration of regrowth delays. Yield losses increased linearly ($r^2 = 0.87$), with larval density up to ca. 1600 larvae/m^2. Further increases in larval density did not cause additional significant losses, with maximal yield losses being about 1/3 of the potential yield of the 40-day regrowth period. Fick also found that regrowth delays caused herbage to be chronologically younger. Therefore, delayed shoots were less mature, shorter in height, and greater in the percentage of leaves, as compared with undamaged shoots. Herbage quality also was better in damaged plants, but the increase in quality was not enough to compensate for the loss in yield. Root carbohydrate levels declined to the same level in all treatments, but reserves did not recover as fast in heavily damaged plants. These findings were essentially similar to the results of the large-scale field studies previously discussed.

In a later study, Fick (1982) assessed the impact of simulated AW defoliation at the first-bud and first-flower stages on subsequent growth and development. Defoliation reduced yield, delayed maturation, reduced stem height, and increased axillary branching. Herbage quality was affected only slightly. The absolute differences in dry matter between damaged and undamaged plants persisted until the end of the study, suggesting that growth rates after defoliation were not inhibited or stimulated by defoliation. Consequently, no compensatory growth occurred. It is unknown, however, whether compensatory growth would occur if plants were defoliated after cutting or during the vegetative growth phase.

Significant delays in alfalfa regrowth also may result from insects with haustellate mouthparts. Newton and Hill (1970) showed that adults of the alfalfa plant bug, Adelphocoris lineolatus (Goeze), tarnished plant bug, Lygus lineolaris (Palisot de Beauvois), meadow spittlebug, Philaenus spumarius (L.), and the leafhopper, Athysanus argentarius Metcalf, retarded regrowth by delaying the initiation of new buds and causing dieback of new shoots. This study, however, was conducted on caged plants in the greenhouse using enormous numbers of insects. It is questionable whether populations on any of these species would ever reach these densities in the field. Nevertheless, reductions in regrowth by piercing-suckling insects are possible and, perhaps, should be investigated in more detail.

PART I. VARIEGATED CUTWORM FOLIAGE CONSUMPTION AND LARVAL DEVELOPMENT ON ALFALFA

ABSTRACT

Variegated cutworm, Peridroma saucia (Hübner), consumption and development on alfalfa was studied in the laboratory. Larvae exhibited either six or seven molts. Larvae with six molts required 35.6 ± 7.1 days (±SD) for development and consumed 352.6 ± 67.5 mg of foliage. Development and consumption by larvae with seven molts were 32.8 ± 3.7 days and 442.2 ± 57.9 mg of foliage, respectively. Larval and adult dry weights indicated that larvae exhibiting seven molts probably were representative of feral individuals. Consequently, data from these larvae were used to develop an alfalfa-consumption model for the variegated cutworm.

INTRODUCTION

The variegated cutworm (VCW), Peridroma saucia (Hübner), is a pest of many vegetable, ornamental, and field crops (Chittenden 1901, Crumb 1929). In some years, VCW in Iowa may cause widespread damage to alfalfa and other crops. Larvae are nocturnal and climb stems to feed on leaves and succulent stems. Damage is caused primarily by the consumption of leaves, petioles, and axillary stems, rather than by severance of main stems.

VCW phenology in Iowa is such that adults lay eggs in alfalfa in late April and early May. Larvae hatch and feed on the spring alfalfa growth. When alfalfa is cut, normally about June 1, many larvae are entering or have entered the last larval stage. Because most consumption in this species occurs during the last larval stage (Berry and Shields 1980), moderate populations of VCW may cause considerable damage to the subsequent regrowth. This damage can result in regrowth delays of several days to 2 weeks or more (Soteres et al. 1984). The objectives of this study were to measure the consumption and developmental time of VCW on alfalfa and to develop a consumption model for this insect on alfalfa.

MATERIALS AND METHODS

All larvae used in this study were the progeny of feral adults collected in blacklight traps located near Ames, Iowa. Eggs obtained from these adults were held in an environmental chamber at 24 ± 0.5°C in a 15:9-h L:D regime. Upon hatching, 50 larvae were placed individually in 76-diam. plastic petri dishes that contained moistened filter paper. Larvae were provided with alfalfa foliage that was kept turgid by placing leaf or branch stems in a 1-dr vial containing water and a cotton plug. Foliage was obtained from a field of 'Valor' alfalfa that was managed to maintain vegetative growth. Larvae that died during the study were replaced with similarly treated larvae of the preceding stage.

Larval development was monitored daily. Molting was confirmed by examining containers for exuviae and by measuring head capsule widths (HCW). Dry-weight consumption also was determined daily by calculating the difference between initial and remaining (final) foliage dry weight (Waldbaurer 1968). Initial dry weight was estimated from the initial foliage fresh weight and the moisture content of an aliquot of control leaves. Final dry weight was measured directly. To reduce error of consumption estimates, the remaining foliage was minimized by providing small, medium, and large larvae with single leaflets, leaves, and lateral branches containing several leaves, respectively.

Beginning with the fourth stage, larval fresh weight was measured after each molt, and pupal fresh weight was measured 2 days after pupation. Larval and pupal dry weights were estimated on the basis of

moisture content of a similarly treated cohort of control larvae. Dry weight of adults was measured directly 1 day after eclosion. Student's t-tests indicated that most parameters were not significantly ($P = .05$) affected by gender. Therefore, unless otherwise indicated, results for males and females were combined, and all data are presented as means ± 1 standard deviation.

RESULTS AND DISCUSSION

Mortality was low throughout the study, with stage-1 larvae, prepupae, and pupae having the highest rates (5.2, 4.0, and 4.8%, respectively). Furthermore, 38.6% of larvae exhibited 6 stages and 61.4% of larvae underwent 7 larval stages. Although VCW typically exhibits 6 larval stages (Capinera 1978, Berry and Shields 1980, Simonet et al. 1981), Snyder (1954) found that VCW may undergo supernumary molts when reared on certain host plants, with 11% of larvae fed alfalfa exhibiting a 7th stage.

The number of larval stages (hereinafter called mode) had no significant ($P > .05$) effect on stages 1-4, total larval, and pupal stadia (Table 2). In fact, mode-7 larvae required an average of 2.8 days less than mode-6 larvae to complete larval development. Stadia of stages 5 and 6 were significantly longer for mode-6 larvae than mode-7 larvae. The combined duration of stages 6 and 7 for mode-7, however, was not significantly different from the duration of stage 6 for mode-6 larvae. Irrespective of mode, all larvae underwent a 3-day prepupal phase. Because little or no feeding occurred during this time, the duration of feeding by ultimate-stage larvae was 17.4 and 11.4 days for mode 6 and 7 larvae, respectively.

The developmental times observed in this study are comparable with those observed by other researchers. Rearing larvae at 25°C, Snyder (1954) reported larval developmental times of 30.9 days for an overall mean of 12 host plants and 26.9 days on alfalfa. Tomescu et al. (1978) found that larval development on an unspecified artificial diet required

Table 2. Stadia (days) of variegated cutworms reared on alfalfa foliage with 6 and 7 total larval stages

Stage	Mode[a]	
	6	7
1	3.0 ± 0.2a	2.8 ± 0.4a
2	2.1 ± 0.2a	2.0 ± 0.2a
3	2.7 ± 0.5a	2.6 ± 0.5a
4	2.9 ± 0.3a	2.9 ± 0.3a
5	4.5 ± 0.6a	3.7 ± 0.6b
6	20.3 ± 7.1a	4.4 ± 0.7b
7	---	14.4 ± 3.2
1-7	35.6 ± 7.1a	32.8 ± 3.7a
Pupa	13.2 ± 0.8a	13.6 ± 0.8a

[a]Means within a row followed by the same letter are not significantly different (P = .05); Student's t-test.

30 days at 24°C. Additionally, stages 2-6 required 27.5 days to complete development at 27°C on sugarbeet foliage (Capinera 1978), and stages 3-6 required 21.9 days at 25°C when fed peppermint foliage (Berry and Shields 1980).

Mean total consumption for mode 6 and 7 larvae was 352.6 ± 67.5 and 442.2 ± 57.9 mg, respectively. Stage-specific and total consumption were greater for females than males, but none of these differences was statistically significant. Consumption also was similar among modes during the first 4 larval stages; thus, differences in total consumption

developed from stage 5 to pupation (Table 3). Even though mode-7 larvae consumed 75% of their total consumption during the 7th stage, ca. 95% of total consumption of both modes occurred from stage 5 to pupation. Berry and Shields 1980) also found that 94% of total consumption of peppermint foliage occurred between stage 5 and pupation. Although VCW consumption of peppermint (Berry and Shields 1980) and sugarbeet (Capinera 1978) has been determined, these data are not directly comparable with the results of the present study, because consumption in these other studies was measured as leaf area and not dry weight. Nevertheless, if the value of 130.8 cm^2 for consumption of sugarbeet foliage is multiplied by the specific leaf weight of sugarbeet (3.8 mg/cm^2; Capinera et al. 1981), a value of 497.0 mg results. This value is only 12% larger than the consumption measured for mode-7 larvae in the present study.

Average daily consumption (ADC) more than doubled with each successive larval molt (Table 3). Mode did not significantly affect ADC for any stage, except stage 5. This difference, however, was not numerically large. Because both modes consumed foliage at approximately the same daily rate, most of the differences in stage-specific consumption were caused by differences in larval developmental times and not in ADC.

Measurements of larval dry weight indicated that mode-6 larvae were significantly heavier than mode-7 larvae at the beginning of stages 4, 5, and 6 (2.2 ± 0.5, 6.6 ± 1.7, and 18.5 ± 3.9 mg for mode 6; 1.8 ± 0.6, 5.3 ± 1.5, and 14.5 ± 2.6 mg for mode 7, respectively). Mode-7 larvae, however, weighed 33.6 ± 6.7 mg at the beginning of the 7th stage. Furthermore, mode-7 pupae and adults weighed 58.4 ± 8.6 and 41.2 ± 8.5 mg and were 33 and 38% heavier than mode-6 pupae and adults, respectively.

Table 3. Dry-weight consumption and average daily consumption (ADC) of alfalfa by the variegated cutworm

Larval stage	Consumption (mg)[a]		Average daily consumption (mg/day)[a]	
	6	7	6	7
1	0.9 ± 0.4a	1.0 ± 0.5a	0.3 ± 0.1a	0.3 ± 0.2a
2	1.5 ± 0.7a	1.6 ± 1.0a	0.7 ± 0.4a	0.8 ± 0.5a
3	5.3 ± 1.4a	4.9 ± 1.6a	1.9 ± 0.4a	1.8 ± 0.5a
4	11.3 ± 2.7a	10.2 ± 2.9a	3.9 ± 0.8a	3.5 ± 0.9a
5	35.4 ± 7.7a	23.2 ± 4.7b	8.0 ± 1.8a	6.3 ± 1.0b
6	296.7 ± 61.5a	80.2 ± 24.5b	18.5 ± 4.7a	17.8 ± 3.7a
7	---	321.2 ± 43.0	---	29.8 ± 6.7
Total	352.6 ± 67.5a	442.2 ± 57.9b	---	---

[a]Means within a row followed by the same letter are not significantly different (P = .05); Student's t-test.

Trends in HCW were similar to dry weight trends in that mode-6 larvae had significantly larger HCW than mode 7 larvae during stages 5 and 6 (1.97 ± 0.05 and 2.79 ± 0.11 mm for mode 6; 1.87 ± 0.07 and 2.49 ± 0.11 mm for mode 7, respectively). Mode-7 larvae, however, had a mean HCW of 3.31 ± 0.11 mm during the last larval stage. HCW of stages 1 through 4 were not significantly different between modes.

Comparison of these HCW with HCW of a cohort of feral last-stage larvae indicated that mode-6 larvae were significantly ($P < .05$) smaller than the feral cohort, but mode-7 larvae were not significantly different from the feral group. Likewise, a comparison of pupal (from the

feral larvae) and adult (collected in blacklight traps) dry weights showed that mode-6 pupae and adults were significantly ($P < .05$) lighter than the feral group. Mode-7 pupae and adults, however, were not significantly ($P > .05$) different from the feral cohorts. These results suggest that mode-7 larvae are representative of larvae in the field, whereas mode-6 larvae probably are not typical.

Consequently, a foliage-consumption model was developed by using data for the mode-7 larvae. Cumulative dry matter consumption (mg) was regressed on developmental time expressed as cumulative centigrade degree-days (CDD) from hatch, and the following equation was generated (Fig. 1):

$$\text{Consumption} = 29.6314 - 0.5552\ (\text{CDD}) + 0.00251\ (\text{CDD})^2 \quad R^2 = .9995$$

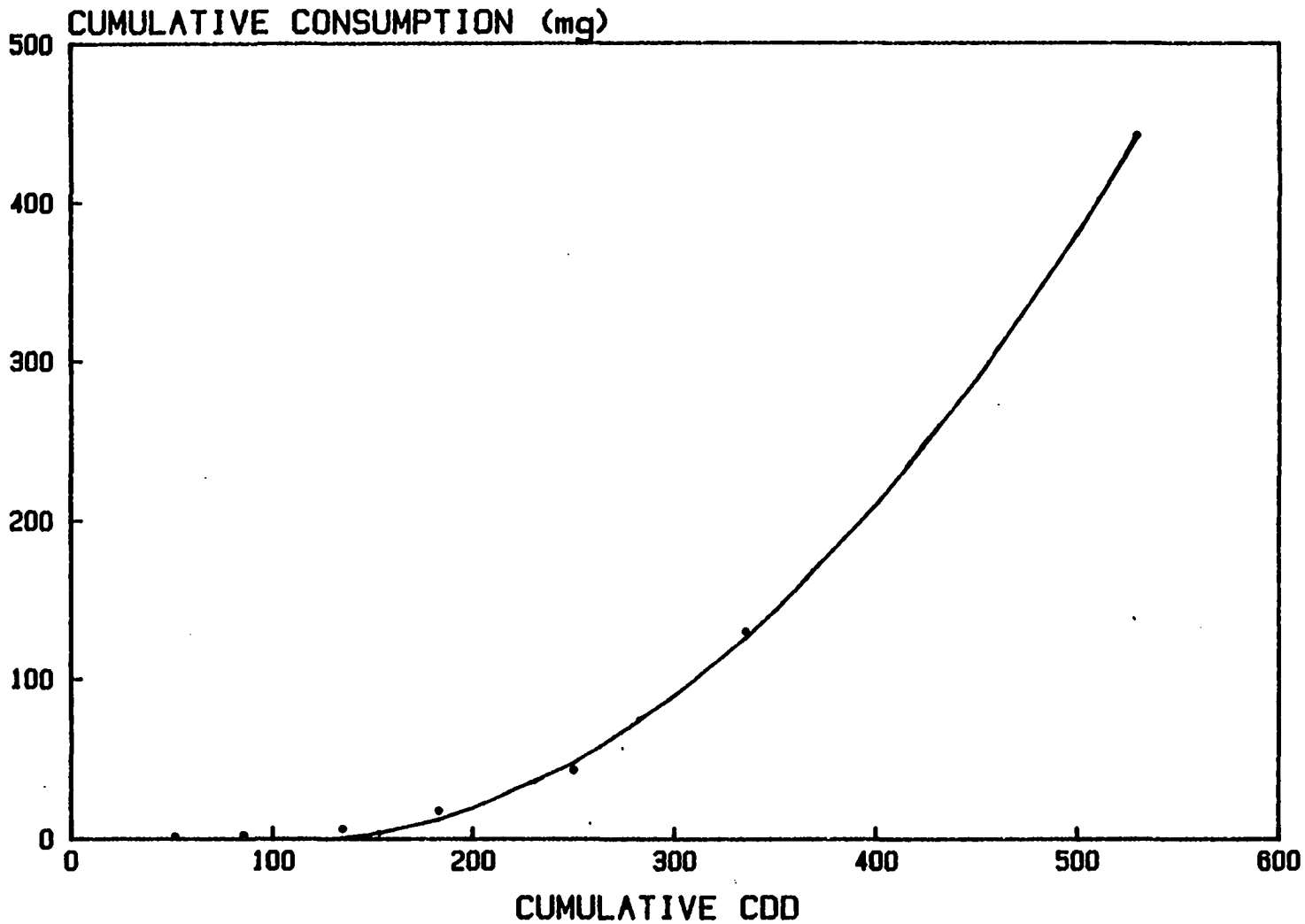
CDD were calculated with a 6.2°C base temperature (Simonet et al. 1981), and larval development did not include the prepupal phase.

The consumption model indicated that about 58 mg of foliage, or 13.3% of total consumption, was consumed during the first half of larval development. Additionally, 50% of total consumption occurred during the last 22.6% of larval development. The majority of foliage consumption by VCW occurred during the last larval stage. Consumption before the last stage amounted to ca. 120 mg, which represents 25% of total consumption.

The results of this study, therefore, suggest that, if alfalfa is cut before most larvae have entered the last larval stage, the damage potential of VCW to the first harvest of alfalfa probably is not great. However, because of the high rate of consumption by last-stage larvae,

the presence of a small number of these larvae after cutting may cause considerable immediate damage to alfalfa regrowth.

Figure 1. Cumulative dry-matter consumption of alfalfa foliage by P. saucia as a function of cumulative centigrade degree-says (CDD)


CUMULATIVE CONSUMPTION (mg)
500
400
300
200
100
0
0
100
200
300
400
500
600
CUMULATIVE CDD

PART II. ALFALFA DEVELOPMENT, DRY MATTER ACCUMULATION AND PARTITIONING AFTER SURROGATE INSECT INJURY OF STUBBLE

ABSTRACT

The effects of regrowth delays after the first cutting on rates of growth, development, and resource partitioning of alfalfa, Medicago sativa L. 'Valor', were investigated in a 2-year study. Damage was designed to mimic insect injury sufficient to cause complete regrowth delays of 1, 3, 7, and 11 days. Dry matter production was very low for the first 3 days of regrowth. Herbage production increased greatly from day 3 to day 7, and remained high after day 7. Regrowth delays of 1 and 3 days did not significantly delay plant development or significantly alter rates of growth and partitioning. Delays of 7 and 11 days retarded plant development and suppressed crop growth rate (CGR) of subsequent regrowth. An 11-day delay reduced CGR by 18.4%, but nearly all of this reduction was caused by a reduction in growth of leaf-support structures. Leaf weight and leaf area growth rates were not significantly affected by regrowth delays. Consequently, plants delayed for more than 3 days, partitioned more leaf area per unit of dry weight through the allocation of greater leaf weight per unit of total weight and greater leaf area per unit of leaf weight. A delay of 11 days resulted in increases of 34.5%, 16.3%, and 15.9% for leaf area ratio, leaf weight ratio, and specific leaf area, respectively. These increases were accomplished through the production of larger but thinner leaves, which enhanced leaf area more than leaf weight. These results are discussed in terms of source-sink relationships within damaged and undamaged plants.

INTRODUCTION

Alfalfa is attacked by a number of insect defoliators. As populations approach economic levels, cutting often is recommended as an alternative method of control. If control is not entirely effective, stubble feeding by surviving individuals may result in delays in alfalfa regrowth of two weeks or more. Regrowth delays after cutting most often are associated with defoliation by the alfalfa weevil (AW), Hypera postica (Gyllenhal), and the variegated cutworm, Peridroma saucia (Hübner) (Fick 1976, Sotores et al. 1984, USDA 1957-1975).

Stubble damage by AW is most common in the northern part of the insect's range, where the species overwinters as an egg or adult. In these areas, larval populations usually reach their peak about the time of first cutting in early June. In a study of the season-long effects of AW damage on alfalfa growth and yield under 2- and 3-cut systems, yield was reduced significantly only during the second cutting of the 3-cut system (Liu and Fick 1975). Many larvae were still active after the first cutting and caused substantial stubble damage. Regrowth was delayed for 5 to 15 days, and damage was sufficient in one year to reduce second growth yield by 31% and total seasonal yield by 17%. Fick (1976) suggested that stubble damage may be the most important management problem of AW in the northern US.

Regrowth delays after the first, and sometimes second, cutting also are reported from the southern and central Great Plains as a result of stubble feeding by the variegated cutworm (USDA 1957-1975). Stubble feeding by this species, however, has not been previously investigated.

A number of other defoliators also have the potential of damaging alfalfa regrowth, including the armyworm, Pseudoletia unipuncta (Haworth), army cutworm, Chorizagrotis auxiliaris (Grotė), dingy cutworm, Feltia subgothica (Haworth), and darksided cutworm, Euxoa messoria (Harris) (USDA 1957-1975, USDA 1979, Walkden 1950).

The effect of stubble feeding on alfalfa regrowth has not been investigated extensively. Studies with AW (Liu and Fick 1975, Fick and Liu 1976, Fick 1976), have found that herbage of damaged plants were less mature, shorter in height, lower in dry weight, but greater in leaf percentage, in vitro digestibility, and crude protein when compared with undamaged plants. This increase in herbage quality did not offset the loss in dry matter. Fick (1976) concluded that most differences in herbage characteristics were the result of differences in herbage maturity at the time of harvest. Although root carbohydrate levels of damaged plants declined to similar levels as in undamaged plants, root carbohydrate reserves did not recover as rapidly in delayed plants. This effect persisted until the next cutting, but was not severe enough to reduce regrowth during the following growth cycle.

No studies have specifically examined the response of component growth rates and resource partitioning by alfalfa to insect-induced regrowth delays. Reduced levels of available carbohydrates during initial regrowth may alter subsequent rates of growth and partitioning of dry matter in regrowth of damaged plants. Depending on the magnitude of these alterations, initial losses could be ameliorated or magnified at the following harvest. The present study was conducted to determine the effect of insect-induced regrowth delays of various durations on the

subsequent rates of growth, development, and resource partitioning by alfalfa.

MATERIALS AND METHODS

The experiment was conducted in a 1.7-ha field located on a Webster silty clay loam (fine loamy, mixed, mesic Typic Haplaquoll) at the Johnson Research Farm, 2.5 km south of Ames, Iowa. Alfalfa, Medicago sativa L. 'Valor', was drill-planted in 17.5-cm rows at the rate of 13.5 kg/ha of seed on 20 Aug., 1980. No fertilizer was applied at planting, but top-dress applications of 135 kg/ha of phosphorous and 225 kg/ha of potassium were made during the spring of each year. The experiment was conducted during the second and third growth cycles in 1981 and 1982. Trials were begun on 1 and 30 June in 1981 and on 1 June and 14 July in 1982. Trials in the same year were located at adjacent sites within the field. Temperature and rainfall data were obtained from a nearby National Oceanic and Atmospheric Administration weather station (No. 0200 05) located 12 km west of the experimental area.

Plots were established within 1 h after cutting. Stubble within plots was clipped to a height of 7 cm, and excess trash and stubble was raked from the plots. A split-plot design was used, with whole plots consisting of duration of complete regrowth delay and split plots being sample dates. Whole plots were arranged in a randomized complete-block design with four replications during the first trial in 1981 and five replications during the other trials. Whole plots were 1.5 m (7 rows) by 3 m and were divided into six subplots, each measuring 0.36 (2 rows) by 1.0 m. The two outer rows and the center row of each plot were treated as border rows and were not harvested.

Insect damage sufficient to cause a complete delay of regrowth was simulated by hand-picking all new herbage within plots every 2 days beginning on day 1 (24 h after cutting). Foliage was picked off at the point of attachment to the stubble or the soil surface. Picking continued in a plot until the desired duration of damage was achieved. The durations of damage were 0 (unpicked), 1, 3, 7, and 11 days post cutting in all trials. A 5-day duration of damage treatment was included in the second trial in 1982. Herbage that was picked from plots damaged for 11 days was collected for dry weight determinations during all trials.

A randomly selected subplot was harvested in each whole plot at 7, 14, 21, 28, 35, and 42 days after cutting during all trials, except the first trial in 1981. The last 2 harvests were not taken during this trial. Plots in all trials, except the first trial in 1981, were sprayed with malathion (0,0-Dimethyl S-(1,2-dicardethoxyethyl) phosphorodithionate) at the rate of 1.1 kg(AI)/ha 1 to 2 days after the 21-day harvest for control of the potato leafhopper, Empoasca fabae (Harris). Subplots were harvested with hand clippers by clipping all above-ground herbage. Old dead stems, leaf litter, and weeds were removed from samples, and the number of stems was counted on all sample dates in 1982 and at the final harvests in 1981.

A representative subsample of 25 stems also was taken from each subplot for detailed analysis. Subsamples were processed in the laboratory and the following parameters measured: stem height, developmental stage, number of main-stem nodes (1982 trials), number of expanded leaves, leaf area, leaf (including petioles and stem tips) dry weight, and support

structure (stem fraction) dry weight. Reproductive structures were included with the support fraction, and leaf area measurements were made with a Li-Cor® brand (Model 3000) leaf planimeter. Plant development was expressed as percentage of stems with bud or flowers, and mean developmental stage was calculated where 1 = vegetative, 2 = bud, 3 = flower and 4 = pod. All samples and subsamples were dried for dry weight measurements in a forced-air oven at 70°C for 72 h.

Statistical Analyses

Treatment differences in all plant variables were analyzed by sample date and trial with an analysis of variance (ANOVA) and Duncan's Multiple Range Test. Results of these analyses are contained in Appendix A. Overall data trends were analyzed with regression techniques. Treatment differences at any point in time, once regrowth began, were determined by a combination of the initial reduction and subsequent changes in plant growth rates. These two sources of loss were evaluated by generating treatment-specific linear regression equations for each plant parameter. Regressions were based on data from harvests when growth was pre-bloom and linearly related to time (i.e., harvest dates 7 through 35). Initial losses were measured by the X-intercepts and are expressed in days. Slopes were compared as a measure of subsequent rates of growth and accumulation (Y) per unit of time (X). Because plant responses may have been influenced by weather conditions during a particular trial, X-intercepts and slopes were calculated for each trial, and results were analyzed with an ANOVA using trials as replicates.

Treatment differences were separated with orthogonal contrasts where: C1 = 0, 1, and 3 versus 7 and 11; C2 = 7 versus 11; C3 = 0 and 1 versus 3; C4 = 0 versus 1. The 5-day duration of damage treatment in trial 2 in 1982 was not included in the analysis. Plant variables analyzed with this approach were accumulation rates of stem height, leaves per stem, leaf area index (LAI), and leaf, support, and total biomass (gm/m^2). Slope values of the last 4 variables represent leaf area growth rate (LAGR), leaf growth rate (LGR), support growth rate (SGR), and crop growth rate (CGR), respectively (Hunt 1978).

Regrowth delay effects on plant partitioning were assessed by calculating the ratios of leaf area and leaf weight per unit of total dry weight and the ratio of leaf area to leaf weight. These ratios are the leaf area ratio (LAR), leaf weight ratio (LWR), and specific leaf area (SLA), respectively, where LAR = LWR × SLA (Hunt 1978). Partitioning ratios were estimated by slopes of regressions of the ratio's components using data from pre-bloom harvests where plant dry weight and leaf area increased linearly with time (i.e., harvest dates 7-35). Data from the same harvest dates also were used to calculate the ratio of leaves per unit dry weight (=leaf number ratio, LNR) and the area and weight per leaf. Partition variables were calculated by treatment for each trial, and analyzed as above with an ANOVA, using trials as replicates.

RESULTS

Precipitation was much below normal during the spring of 1981, which resulted in reduced soil moisture levels at the beginning of both trials. Deviations in rainfall from 30-year averages were -3.30, -8.86, and -4.27 cm for April, May, and June, respectively. Weekly rainfall amounts, however generally were adequate to prevent severe moisture stress during trial 1 in 1981 (Table 4). Little rainfall during the first half of July produced severe moisture stress during the first part of trial 2, which began on July 1. Consequently, plant growth rates were suppressed during this trial. Rainfall and soil moisture levels were near normal during the spring of 1982, and moisture was adequate for normal growth during trial 1 in 1982. Although rainfall was erratic during trial 2 in 1982, soil moisture levels were sufficient to prevent severe moisture stress during this trial.

Initial Growth and Stem Initiation

Herbage picked at 2-day intervals from plots delayed for 11 days revealed that herbage production was suppressed during the first 3 days of regrowth (Fig. 2). The rate of herbage production increased from day 3 to day 7 by a mean of 4.6 times in 1981 and 12.2 times in 1982. The rate of herbage production leveled off after day 7. Although trends were similar in all trials, regrowth occurred at a 2 to 2.5 times greater rate in 1981 than 1982. Furthermore, a large amount of foliage remained on the stubble immediately after both cuttings in 1981, but little foliage was present after the cuttings in 1982. The reason for

Table 4. Summary of precipitation (cm) during weekly growth periods recorded for each trial[a] in 1981 and 1982

Growth period (days)	1981		1982	
	Trial 1	Trial 2	Trial 1	Trial 2
0-7	0.89	1.98	0.61	6.30
8-14	0.23	0.84	0.89	0
15-21	3.02	0	4.32	0.33
22-28	6.25	6.73	0	4.27
29-35	-	1.98	2.34	0.05
36-42	-	6.25	7.75	0

[a]Trials were conducted during the second and third growth cycles in each year, respectively.

the reduction in growth rates between years is unknown, but differences probably were caused, in part, by a reduction in plant vigor that typically occurs during the second year of production (Smith 1975).

Trends in stem density, which was monitored during both 1982 trials, generally were similar in all treatments once regrowth began (Fig. 3). Stem density increased rapidly to a peak during the first 1 to 3 weeks of regrowth and gradually declined from this peak at later harvests. The minimal density needed for a full stand, 375 stems/m^2 (Bula and Hintz 1978), was exceeded in all treatments. Significant reductions in stem density occurred on sample dates 7, 14, and 21 in both trials. Peak stem density, irrespective of date, was significantly ($P < .05$) reduced by regrowth delays of 3, 7, and 11 days during trial 1 and by delays of 7

Figure 2. Dry matter production during the first 11 days of regrowth

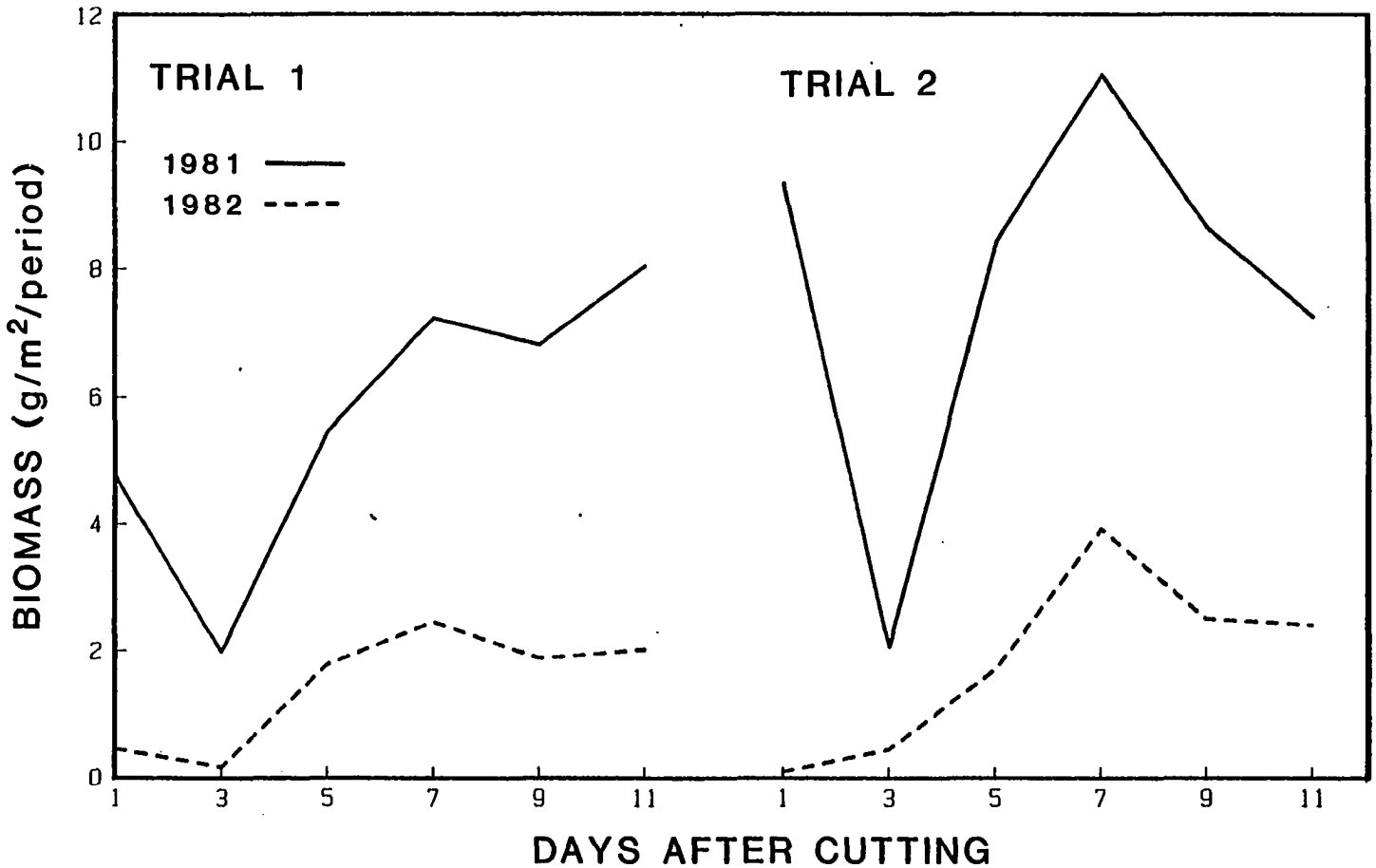
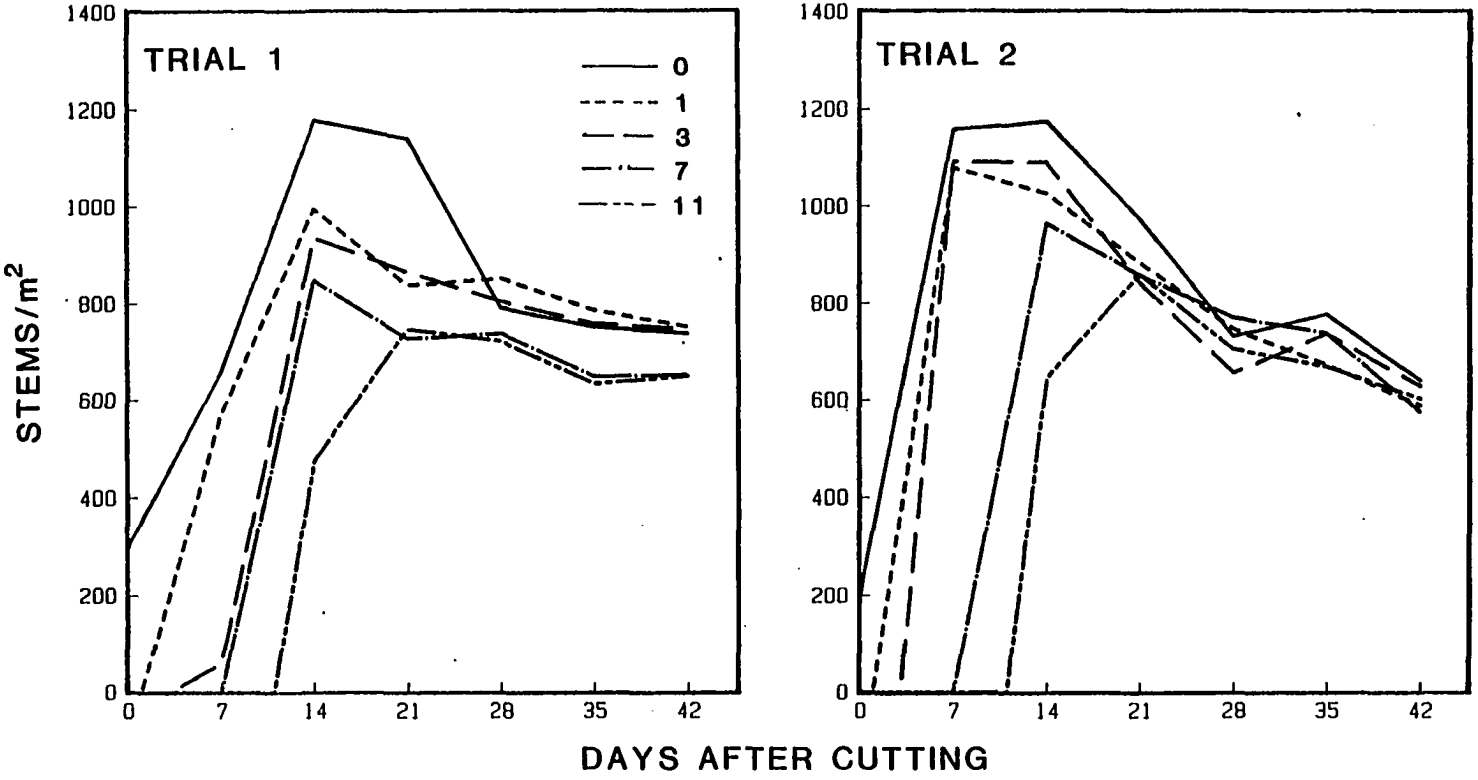

TRIAL 1
TRIAL 2
1981
1982
BIOMASS (g/m²/period)
DAYS AFTER CUTTING
0
2
4
6
8
10
12
1
3
5
7
9
11

Figure 3. Effect of various periods (days) of regrowth delay on alfalfa stem density in 1982


TRIAL 1
TRIAL 2
0
1
3
7
11
STEMS/m²
DAYS AFTER CUTTING
1400
1200
1000
800
600
400
200
0
0
7
14
21
28
35
42

and 11 days during trial 2. Although peak stem density was reduced by regrowth delays, except in one case, no significant treatment differences in stem density occurred from day 28 until the final sample date during either trial. Stem density at the final sample also was not significantly different in trial 2 in 1981, but was significantly greater in the 11-day treatment on day 28 (final sample) in the first trial in 1981 (date not shown). Consequently, large initial differences in stem density were transitory and did not persist through the final sample.

Alfalfa Development and Morphology

Regrowth delays had a substantial effect on the developmental rates of alfalfa. Differences in mean developmental stage were evident by day 14 in both 1981 trials and day 21 in both 1982 trials. Stand maturity on all subsequent dates declined with the length of regrowth delay. Except for trial 2 in 1982, the maturity of plants delayed for 0, 1, and 3 days was not significantly different from each other on the last three sample dates of any trial. Development during trial 2 in 1982 was not significantly affected by a 1-day delay, but was reduced by a 3-day delay on all dates except the final sample. The maturity of plants damaged for 7 and 11 days was delayed significantly in all trials. Furthermore, these treatments generally were significantly different from each other.

Differences in herbage production during the first 3 days of regrowth suggest that a 1-day delay in regrowth may not coincide with a 1-day delay in plant development. To explore this relationships, the number of days from cutting to first bloom was used as a measure of the time required

to reach a particular developmental stage. Days to first bloom were estimated by solving a linear or quadratic equation, whichever described the data best, of percentage bloom against time. Results of this analysis (Table 5) indicate that regrowth delays of 1 and 3 days did not significantly increase the number of days to first bloom. Delays of 7 and 11 days caused a significant increase in days to first bloom, as compared with nondefoliated plants. Plants defoliated for 11 days were delayed significantly longer than 7-day defoliated plants in 3 of 4 trials. The mean increase in the number of days to bloom, however, was less than the actual duration of damage. An average of 0.22, 1.15, 3.41, and 8.46 extra days were required for bloom to occur in plants where regrowth was delayed for 1, 3, 7 and 11 days, respectively. Therefore, the 3-day regrowth delay treatment caused only a 1-day delay in first bloom. Likewise, plants delayed for 7 and 11 days reached first bloom approximately 3 days sooner than expected, based on the actual period of defoliation.

The effects of regrowth delays on alfalfa biomass and LAI in 1982 are shown in Figures 4 and 5 (1981 data is not presented). Regrowth delays caused substantial reductions in alfalfa biomass and LAI on most sample dates. Both biomass and LAI increased linearly in all treatments once damage had ceased. Absolute differences in biomass tended to remain the same or increase over time. The rate of increase in LAI moderated during the last growth period of each trial (except trial 1 in 1981) for plants delayed for 0, 1, and 3 days. This lack of increase in LAI during the last growth period probably reflects a combination of the reduced

Table 5. Predicted date (days after cutting) of first bloom for alfalfa with regrowth delays of various periods

Regrowth Delay (days)	1981		1982		Mean
	Trial 1	Trial 2	Trial 1	Trial 2	
0	21.00	22.98	35.30	26.05	26.33
1	21.58	23.83	35.30	25.49	26.55
3	22.46	24.25	35.44	27.78	27.48
7	28.00	25.47	35.58	29.91	29.74
11	30.41	28.49	40.25	39.54	34.66
Contrasts[a]					
0-3 vs. 7-11	**	**	**	**	**
7 vs. 11	NS	*	**	**	**

[a]Contrasts of 0, 1, and 3 days delays are not significant for any trial; NS = not significant; * and ** are significant at the .05 and .01 levels, respectively.

vegetative growth associated with the shift from vegetative to reproductive phases of development and the senescence of older main-stem leaves (Fuess and Tesar 1968, Nelson and Smith 1968a).

Analysis of Growth and Partitioning

Analysis of initial components of loss, as measured by X-intercepts, is shown in Table 6. Delays of 1 and 3 days did not significantly affect the X-intercepts of any plant variable. Delays of 7 and 11 days caused

Figure 4. Response of alfalfa leaf area index (m^2/m^2) to various periods (days) of regrowth delay in 1982

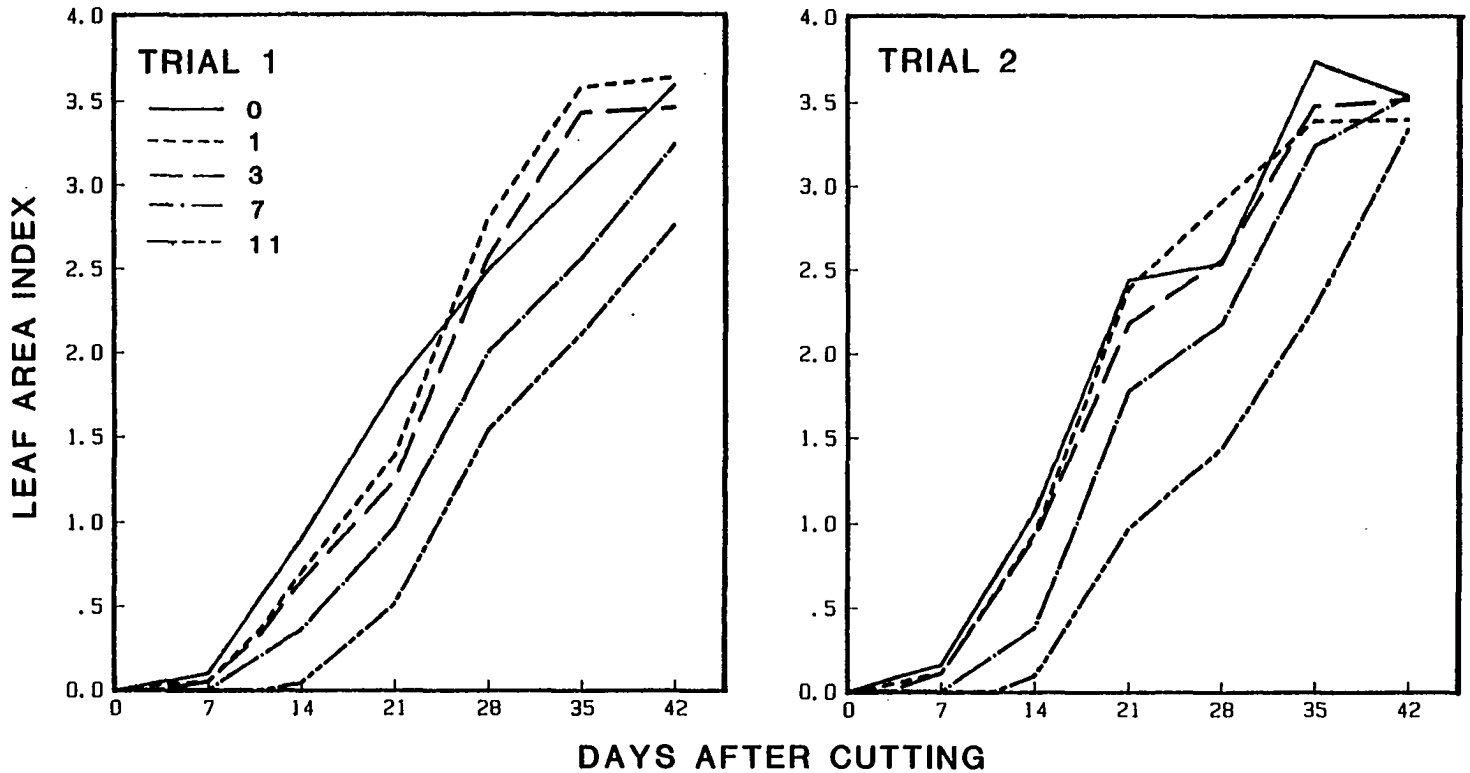

TRIAL 1
0
1
3
7
11
TRIAL 2
LEAF AREA INDEX
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0.0
0
7
14
21
28
35
42
DAYS AFTER CUTTING

Figure 5. Response of alfalfa biomass (kg/ha) to various periods (days) of regrowth delay in 1982

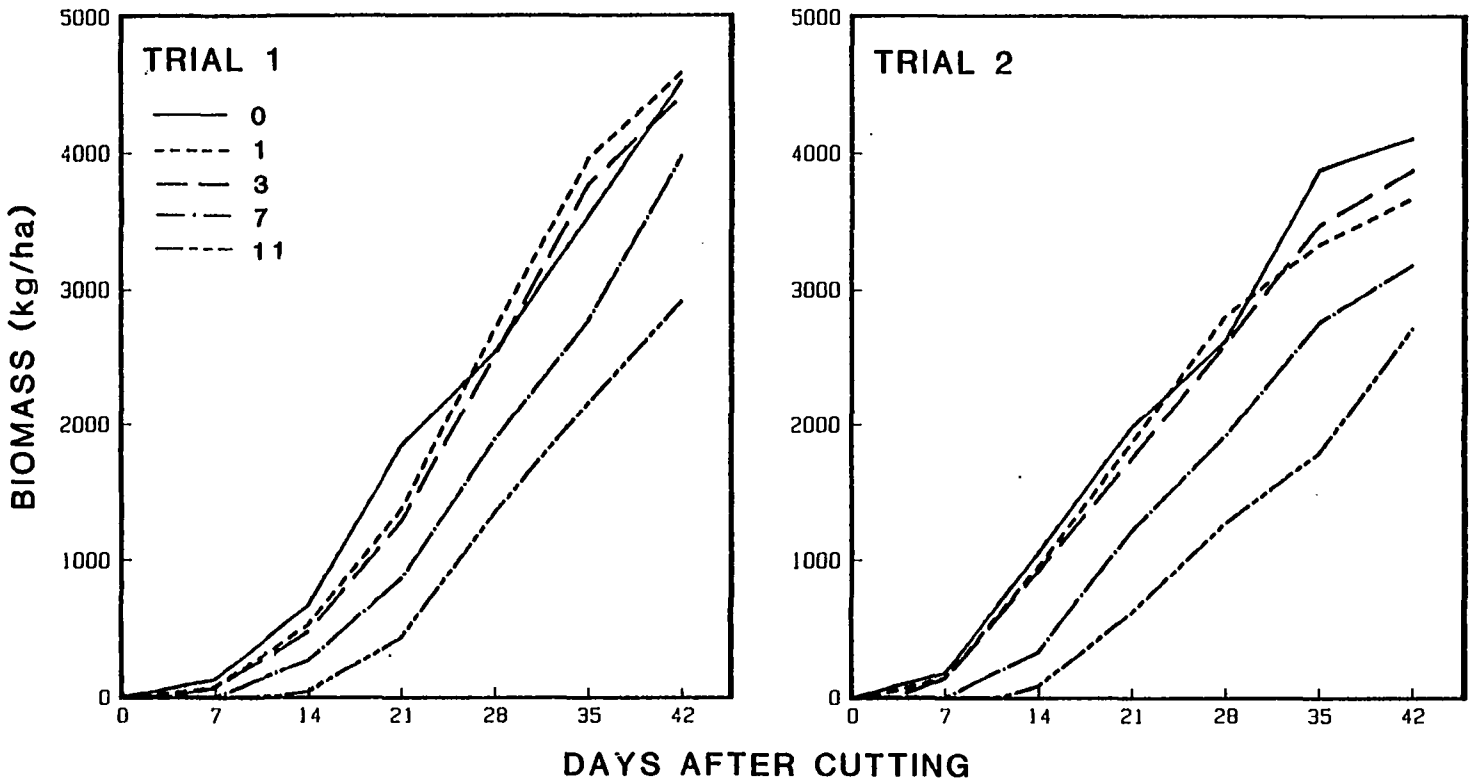

TRIAL 1
TRIAL 2
0
1
3
7
11
BIOMASS (kg/ha)
5000
4000
3000
2000
1000
0
0
7
14
21
28
35
42
DAYS AFTER CUTTING

Table 6. Effects of various lengths of alfalfa regrowth delay on the X-intercepts from the regressions of six plant variables against time (days)

Regrowth delay (days)	Stem height	Leaves/ stem	Biomass			Leaf area
			Leaf	Support	Total	
0	1.35	5.55	0.07	4.51	2.63	2.08
1	2.19	5.67	2.34	5.51	4.14	4.53
3	3.56	6.06	2.84	5.86	4.53	5.47
7	8.29	9.87	6.43	10.11	8.50	9.75
11	12.68	12.33	12.44	13.87	13.18	13.90
Contrasts[a]						
0-3 vs 7-11	**	**	**	**	**	**
7 vs 11	*	**	*	*	*	*

[a]Contrasts of 0, 1, and 3 days delay are not significant for any variable; * and ** are significant at the .05 and .01 levels, respectively.

significant ($P < .01$) increases in the X-intercepts of all plant variables, when compared with the other treatments. Additionally, an 11-day delay caused a significant ($P < .05$) increase in the X-intercept of all variables as compared with a 7-day delay. These results suggest that regrowth delays greater than 3 days were needed to cause significant initial losses in all plant variables. Longer regrowth delays produced similar initial losses in all measured plant parameters. The lack of effect on initial growth caused by delays of 1 and 3 days probably is the result of the greatly reduced rate of growth during the first 3 days of regrowth.

Table 7. Regrowth delay effects on the accumulation of stem height and leaves per stem and on leaf growth rate (LGR), support growth rate (SGR), crop growth rate (CGR), and leaf area growth rate (LAGR) of alfalfa

Regrowth delay (days)	Stem height (cm/day)	Leaves/ stem (No/day)	Biomass ($gm/m^2/day$)			LAGR ($m^2/m^2/day$)
			LGR	SGR	CGR	
0	1.444	1.298	0.0467	0.0656	0.1123	0.1074
1	1.419	1.202	0.0484	0.0655	0.1139	0.1170
3	1.437	1.185	0.0466	0.0625	0.1091	0.1116
7	1.515	1.197	0.0440	0.0591	0.1032	0.1160
11	1.548	0.956	0.0447	0.0469	0.0916	0.1168
Contrasts[a]						
0-3 vs 7-11	NS	**	NS	**	**	NS
7 vs 11	NS	**	NS	*	NS	NS

[a]Contrasts of 0, 1, and 3 days delay are not significant for any variable; NS = not significant; * and ** are significant at the .05 and .01 levels, respectively.

The effects of simulated regrowth delays on the subsequent rates of accumulation are shown in Table 7. Delays in regrowth had no significant effect on subsequent rates of accumulated stem height. The same also was true for nodes per stem during the two trials in which this variable was measured (data not shown). The accumulation rate of leaf number per stem, however, declined significantly when regrowth was delayed for 7 and 11 days. Because the number of main-stem nodes was not affected by regrowth treatments, the reduction in the accumulation rate of leaves

per stem probably was caused by a reduction in axillary leaf production and branching.

Increasingly longer regrowth delays caused proportional reductions in CGR (Table 7). Delays of 7 and 11 days significantly reduced CGR when compared with shorter delays. The reduction in CGR between delays of 7 and 11 days, however, was not statistically significant. Almost all of the reduction in CGR was attributable to a decline in SGR. Delays of 7 and 11 days significantly reduced SGR, and the difference in SGR between these treatments also was significant. Leaf growth rate was not significantly affected by any treatment. An 11-day delay caused a decline of 4.3% in LGR and 28.5% in SGR compared with an 18.4% reduction in CGR. As with LGR, LAGR was not significantly affected by any treatment, and LAGR was actually 8.8% greater in plants delayed for 11 days than in nondefoliated plants.

The greater deleterious effect of regrowth delays on SGR than LGR and LAGR suggests that damaged plants may partition resources differently than undamaged plants. Trends in LAR, LWR, and SLA confirm this suggestion (Table 8). Although delays of 1 and 3 days had no significant effect on LAR, LWR, or SLA, delays of 7 and 11 days significantly increased LAR by 21.3 and 34.5%, respectively. The increase in LAR between the 7 and 11 day treatments also was significant. Delays of 7 and 11 days also significantly enhanced LWR and SLA. An 11-day delay caused LWR and SLA to increase by 16.3 and 15.5%, respectively. Therefore, LAR was enhanced by a combination of an increase in both LWR and SLA. In other words, plants delayed for more than 3 days produced greater leaf area per unit of dry weight by increasing leaf weight at the expense of support

weight and by producing greater leaf area per unit of leaf weight. The latter consequence results in thinner, less dense leaves. The component growth analysis, however, indicated that the decline in LWR was the result of a reduction in support weight relative to leaf weight production rather than an increase in leaf weight per se.

The increase in LWR (i.e., the maintaince of leaf weight production in delayed plants) could be accomplished by producing more leaves per unit of dry weight (i.e., greater LNR) or by producing larger leaves. Leaf number ratio was not significantly different for any treatment, thus, leaf production declined in direct proportion with total dry weight (Table 8). Area and weight per leaf, however, increased significantly in plants delayed for 7 and 11 days, although area was enhanced more than weight. This would be expected because of the increased SLA in plants delayed for more than 3 days. Therefore, LWR increased by the production of larger leaves rather than the production of more leaves per unit of dry weight.

Table 8. Effects of various lengths of regrowth delay on alfalfa leaf area ratio (LAR), leaf weight ratio (LWR), specific leaf area (SLA), leaf number ratio (LNR), and area and weight per leaf

Regrowth delay (days)	LAR (cm^2/gm)	LWR (gm/gm)	SLA (cm^2/gm)	LNR (No/gm)	Area/ leaf (cm^2)	Weight/ leaf (mg)
0	94.8	0.415	227.0	56.89	1.77	7.71
1	102.1	0.416	241.1	57.85	1.83	7.54
3	101.1	0.420	239.0	58.89	1.81	7.40
7	115.0	0.436	260.8	58.24	2.11	7.93
11	127.4	0.482	262.2	56.16	2.34	9.18
Contrasts[a]						
0-3 vs 7-11	**	**	**	NS	**	**
7 vs 11	*	**	NS	NS	*	**

[a]Contrasts of 0, 1, and 3 days delay are not significant for any variable; NS = not significant; * and ** are significant at the .05 and .01 levels, respectively.

DISCUSSION

Complete regrowth delays of 1 and 3 days caused no significant initial loss in any plant variable, as measured by X-intercepts. Furthermore, subsequent rates of growth and partitioning were not significantly affected by these treatments. The lack of effect of these delays probably is a consequence of the low rate of crop growth during the first 3 days of regrowth. Herbage production was substantially greater after the third day, and growth rates remained elevated until the eleventh day. The 3-day lag in regrowth occurred in all 4 trials. Plants delayed for more than 3 days seemed to produce herbage at the higher rate of production immediately, thereby, avoiding the initial 3-day lag in regrowth.

Previous studies (Pearce et al. 1969, Vance et al. 1979) of carbon flow in alfalfa following cutting have found approximately a 3-day lag in root carbohydrate mobilization following cutting. Starch levels and percentage of ^{14}C in taproots declined sigmoidally after cutting, with the latter showing a decline of only 4% from day 0 to 3 and a 9% decline from day 3 to 6 (Pearce et al. 1969). Stored root starch did not decline significantly until the sixth day of regrowth. Pearce et al. interpreted these findings as indicating that approximately 3 days were needed for the plant to switch from starch synthesis before cutting to starch degradation and mobilization following cutting. During this time, proteins needed for stored carbohydrate mobilization and utilization were being produced. This lag time in carbohydrate mobilization may explain the approximately 3 days of low herbage production observed in the present study. It is also possible that basal and axillary buds simply may require several days to develop and initiate new growth.

Complete delays in regrowth of more than 3 days significantly delayed plant development and caused significant initial reductions in all plant parameters. Plant development, however, was delayed less than expected based on the actual length of defoliation. Again, this probably was the result of the reduced growth rate during the first 3 days. This damage also was sufficient to reduce subsequent growth rates and alter resource partitioning. Initial reductions in support and total biomass and leaves per stem were magnified further by significant declines in the rates of production of these components. Although CGR was suppressed, most of the reduction in biomass production was caused by a decline in the support component growth rate. The leaf component was not significantly affected, and the production rate of LAI actually increased slightly in regrowth-delayed plants. Defoliation of more than 3 days, however, resulted in reduced leaf density. This would have the effect of enhancing the area available for light interception without a concomitant increase in leaf biomass. Alfalfa, therefore, minimized the adverse effects of insect-induced regrowth delays by maintaining leaf area and leaf-weight growth rates at the expense of the support structure component of growth.

The differential effects on component growth rates and plant partitioning in plants delayed for more than 3 days may be, at least in part, the result of an alteration in carbohydrate source-sink relationships. In undamaged plants, two sources of carbohydrates are normally available for regrowth; stored root reserves and photosynthates produced by current photosynthesis. Although current photosynthates will be used preferentially during regrowth (Hodgkinson 1969), relatively low

availability of this source necessitates the use of stored reserves as the primary source of carbon for about the first 3 weeks of regrowth (Hodgkinson 1969, Pearce et al. 1969, Smith and Marten 1970). Hodgkinson (1969), however, found that new leaves import stored carbon only during the first week or so of regrowth. Leaves generally become self-sufficient after this time and begin exporting photosynthates. Support structures, on the other hand, continue to rely on stored carbon for about 21 days. After this time, stored carbohydrates are reduced and support structures must rely mainly on current photosynthates for growth.

It is probable that subsequent regrowth, in plants where regrowth is delayed for 8 to 10 days, would occur without the benefit of large amounts of stored carbohydrates. The primary carbohydrate source for regrowth most likely would be shifted from stored carbohydrates to currently produced photosynthates. Consequently, leaf growth by delayed plants should be affected much less than support growth because: (1) leaves, in comparison with support structures, require relatively little imported carbohydrate, and, (2) sources (i.e., leaves) generally will meet their own needs before exporting assimilates (Cook and Evans 1978). Support growth, however, would be suppressed because of the low availability of stored carbohydrates and inability of current photosynthesis to make up the difference. Thereby, leaf growth rates are maintained while support structure growth rates suffer.

PART III. DRY MATTER ACCUMULATION, PARTITIONING AND DEVELOPMENT OF ALFALFA REGROWTH AFTER STUBBLE INJURY BY THE VARIEGATED CUTWORM

ABSTRACT

The impact of stubble feeding by the variegated cutworm (VCW), Peridroma saucia (Hübner), on alfalfa growth, development, and dry matter partitioning during the second growth cycle was investigated in a 3-year study. Densities of 6 or greater larvae/0.1 m^2 completely suppressed regrowth and caused significant delays in the development of subsequent regrowth. Lower densities only partly suppressed regrowth and did not consistently delay plant development. Larval damage produced large reductions in stem density during the first 2 to 3 weeks of regrowth, but these reductions were transitory and did not persist after the third week. Densities of 1.5 and 3 larvae/0.1 m^2 did not consistently affect growth rates or partitioning of subsequent regrowth. Densities of 6 or greater larvae/0.2 m^2 caused regrowth to produce stem height at a significantly faster rate. The rate of production of main-stem nodes was not affected, and the production of leaves per stem declined significantly. Larval damage also suppressed daily rates of dry matter production. Most of this reduction, however, was caused by a reduction in the support component of growth. Leaf growth rate was not suppressed, and leaf area production actually increased in severely defoliated treatments. Damaged plants produced more leaf area per unit of total dry weight through relative increases in both leaf weight per unit of total dry weight and leaf area per unit of leaf weight. Damaged plants seemed to minimize the adverse effects of VCW stubble feeding by maintaining growth rates of leaves at the expense of support structures.

INTRODUCTION

The variegated cutworm (VCW), Peridroma saucia (Hübner), is a pest of a large number of vegetable, ornamental, field, and forage crops (Chittenden 1901, Crumb 1929, Rings et al. 1976b). In the southern and central Great Plains, VCW can cause considerable damage to alfalfa by feeding on new regrowth soon after cutting (Soteres et al. 1984, USDA 1957-1975). If sufficient numbers of larvae are present, stubble feeding by VCW may cause partial or complete delays of regrowth for several days to two weeks or more. VCW phenology is such that many larvae are near maturity when the first cutting is taken in early June. Stubble damage, therefore, usually occurs after the first cutting, but regrowth delays also have been reported after the second cutting in some years (USDA 1975).

The impact of stubble feeding by insects on alfalfa growth and yield has received little attention, and no studies have specifically investigated stubble injury by VCW. Several studies (Fick 1976, Fick and Liu 1976, Liu and Fick 1975) have investigated stubble injury by the alfalfa weevil (AW), Hypera postica (Gyllenhal). Regrowth damage by AW primarily is a problem in the northern part of the insect's range. In these areas, AW overwinters mostly in the egg stage, and larval populations usually reach a peak about the time of the first harvest. A study of the season-long effects of AW on alfalfa in New York found that AW significantly reduced yield only during the second growth of a 3-cut system (Liu and Fick 1975). Yield loss was the result of stubble feeding by larvae after the first cutting. Regrowth was delayed from 5 to 15

days, causing second cut and total seasonal yields reductions of 31 and 17%, respectively.

In a companion study of AW stubble injury (Fick 1976), yield losses increased with larval density up to a plateau, above which greater densities did not cause additional yield losses. Herbage of delayed plants was less mature, shorter in height, and lower in dry weight, but was greater in leaf percentage, in vitro digestibility, and crude protein. The increase in quality was small and not sufficient to offset the loss in dry weight. Fick attributed most of the differences in herbage of defoliated and nondefoliated plants to the relative differences in herbage maturity at harvest.

Stubble feeding by VCW also could have a large impact on alfalfa regrowth. The stress of VCW-induced stubble injury also may alter subsequent rates of growth and partitioning by alfalfa. Therefore, a study was conducted to determine the effects of stubble feeding by VCW on alfalfa regrowth. Presented here are the results of the effects on rates of growth, development, and resource partitioning by alfalfa.

MATERIALS AND METHODS

A stand of 'Valor' alfalfa, Medicago sativa L., was seeded on 20 August, 1980 in a field located 3 km south of Ames, Iowa. Seed was drill-planted in 17.5-cm rows at the rate of 13.5 kg/ha. No fertilizer was applied at planting, but fertilizer was top dressed with 135 kg/ha of P and 225 kg/ha of K before growth in each year. Except when studies were conducted, the field was maintained with management practices typical for central Iowa. Malathion (0,0-Dimethyl S-(1,2-dicarbethoxyethyl) phosphorodithionate) was applied as needed at the rate of 1.1 kg(AI)/ha to control AW during the first cutting. Malathion also was applied at the same rate after VCW feeding had ceased to control the potato leafhopper, Empoasca fabae (Harris). Temperature and rainfall data were obtained from a National Oceanic and Atmospheric Admin. weather station (No. 0200 05) located 12 km west of the experimental area.

Plots measuring 1.5 m (7 rows) by 4 m were established immediately after cutting on 10 June, 1981, 1 June, 1982, and 14 June, 1983. Plots were clipped to a height of 7.5 cm. Excess trash and stubble were raked from the plots. After cutting, each plot was enclosed with a 45-cm aluminum barrier using the procedure employed by Showers et al. (1983). Barriers were implanted to a depth of 15 cm by digging a trench with a mechanical trencher, and care was taken to throw soil away from plot areas. The following evening, plots were infested with various densities of larvae. Larvae for all studies were progeny of feral adults that were collected with modified blacklight traps during the spring of each year. Groups of 25 larvae were reared in 470-ml cartons on a modified

artificial diet of Shorey and Hale (1965), where lima beans were substituted for pinto beans (Harper 1970). All larvae, however, were transferred to a diet of fresh alfalfa foliage 3 to 4 days before infestation. Initial rearing conditions were 24 ± 0.5°C, but as larval development progressed, temperature was varied so that most individuals were newly molted, last stage (6 or 7) larvae at the time of infestation.

A split-plot experimental design was employed where whole plots consisted of larval densities and subplots were samples over time. Whole plots were arranged in a randomized complete-block design with 5 blocks in 1981 and 1982, and 4 blocks in 1983. Larval densities were 0, 1.5, 3, 6, 9, and 12 larvae/0.1 m^2 in all years, except in 1981 when the 1.5 larvae/0.1 m^2 density was not used, and in 1983 when the 12 larvae/0.1 m^2 density was not used. These densities were chosen to represent the full range of VCW densities reported to infest alfalfa stubble (USDA 1957-1975).

In 1981 and 1982, whole plots were divided into four subplots measuring 0.36 m (2 rows) by 1.5 m (0.53 m^2). The outer two rows and the center row of each plot were not sampled as part of the subplots. After larval feeding ceased, one subplot was harvested weekly beginning on day 14 in 1981 and day 21 in 1982. All above-ground herbage was clipped with hand clippers and returned to the laboratory. Dead stems, leaf litter, and weeds were separated from the herbage, and stem density and dry weight were measured. A representative subsample of 25 stems was taken from each subplot for detailed measurements. In 1982, stem density also was measured nondestructively in the 21-day sample subplot on days 4, 8, 12, and 16 after cutting. Additionally, if regrowth was present, a sub-

sample of 25 stems was taken from areas between subplots on days 8, 12, and 16 after cutting.

The split-plot portion of the study was modified in 1983 to specifically examine the interaction between VCW stubble feeding and subsequent weed populations. Whole plots were divided into three 1.0 m^2 subplots. Two subplots were hand-weeded at 21 days after cutting, and natural weed populations were allowed to develop in the third subplot. Alfalfa regrowth was monitored weekly beginning on day 7 in one of the weeded subplots by taking a representative sample of 25 stems. Plant development, shoot dry weight, and forage quality were determined from these samples. Stem density also was measured nondestructively in a randomly chosen half of the other weeded subplot. Weekly yields were estimated from these data, and final yield was determined on day 35 by harvesting the nondestructively sampled subplot. The subplot containing weeds also was harvested on day 35, but the results of the weed interaction portion of the study will not be presented here.

Subsamples for detailed measurements were processed similarly in all years. Parameters measured were stem height, number of main-stem nodes per stem (1982 and 1983), number of expanded leaves, leaf area, and average stage of morphological development (where 1 = vegetative, 2 = bud, 3 = flower, and 4 = pod). Leaf area was measured with a LiCor® model 3000 leaf area planimeter. Subsamples were separated into leaf (including petioles and stem tips) and support fractions to determine their separate dry weights. All herbage was dried in a forced-air oven at 70°C for 72 hours.

Statistical Analyses

All plant parameters were analyzed by year and sample date with and analysis-of-variance (ANOVA) and subsequent Duncan's Multiple Range Test. Parameter means and results of these analyses are contained in Appendix B. An overall ANOVA was conducted by year for plant variables that were linearly related to time. Data used in these analyses were from harvest dates 14 (day 16 in 1982) through day 35 for all years. The design was a split plot, where whole-plot treatment differences were elucidated by orthogonal comparisons. Contrasts used to separate differences in larval densities were: C1 = 0-6 versus 9-12, C2 = 9 versus 12, C3 = 0-3 versus 6, C4 = 0-1.5 versus 3, and C5 = 0 versus 1.5. Contrast C2 was not used in 1983, and C5 was not used in 1981. The linear effect of sample date was examined at the split-plot level, and the orthogonal treatment contrasts by day-linear effects were examined in the interaction. The interaction analysis tested for differences in linear trends (slopes) of treatments over time.

RESULTS

Alfalfa growth rates were suppressed somewhat in 1981 because of below normal soil-moisture levels and less than average precipitation during the first part of the study (Table 9). Rainfall in 1982 and 1983 was near normal or excessive before and during the time both studies were conducted. Consequently, little moisture stress was evident during 1982 and 1983. Mean deviation from 30-year averages in rainfall from April through June was -16.13, -1.96, and +5.60 cm in 1981, 1982, and 1983, respectively.

Damage Syndrome and Stem Initiation

Larval feeding occurred for ca. 12 days in 1981 and 1983 and for about 14 days in 1982. Densities of 9 and 12 larvae/0.1 m^2 consistently caused complete delays in regrowth in all years. Few new shoots grew in these plots while feeding occurred, and the few shoots that did grow were severely damaged. Feeding scars also were present on the old stubble. Densities of 1.5 and 3 larvae/0.1 m^2 caused partial damage to regrowth in all years. Feeding evidence on most shoots was reflected as wholly or partly missing leaves and leaflets. Damage, however, usually was not severe enough to cause noticeable stunting of the shoots. Densities of 6 larvae/0.1 m^2 produced intermediate results in that regrowth was completely delayed in some plots, whereas others had some regrowth present while defoliation was occurring. Shoots that did grow, however, were severely damaged. Most leaf lamina were absent, and shoots were severely stunted, with the apical meristem often removed. Larval feeding

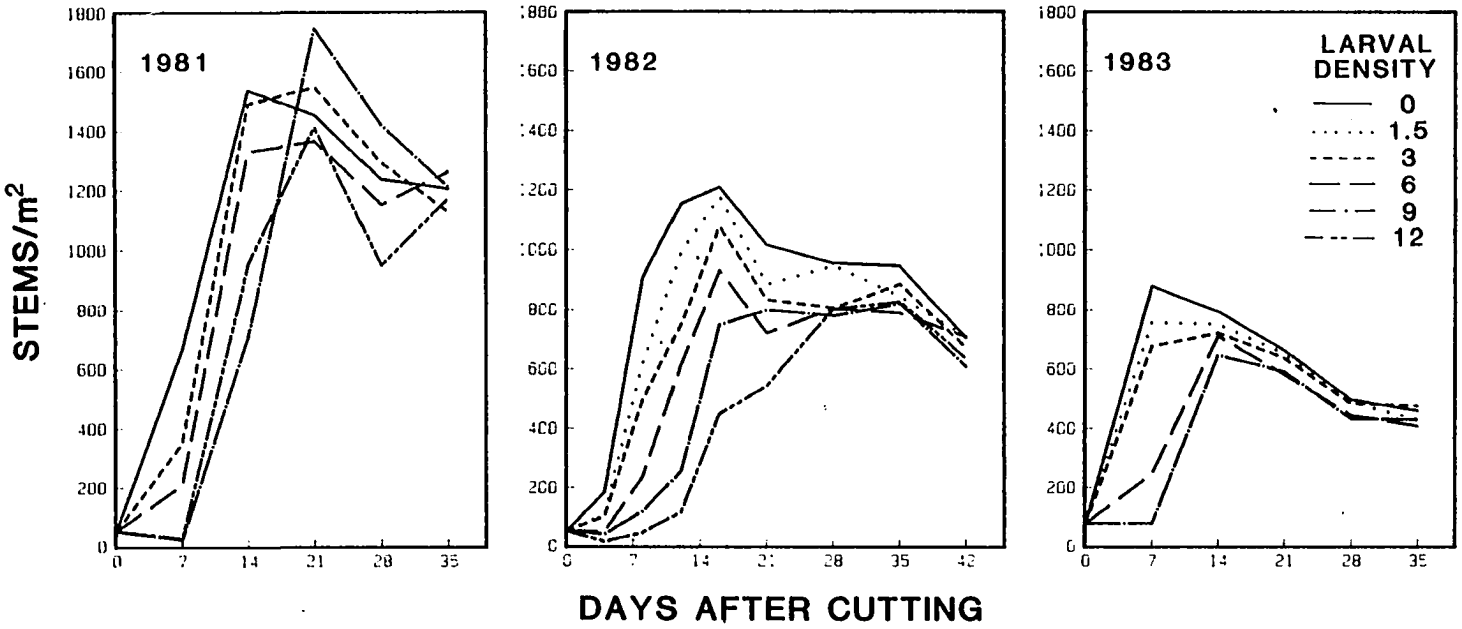
Table 9. Weekly precipitation (cm) during the 3 year study

Days after cutting	1981	1982	1983
0-7	1.98	0.61	2.06
8-14	0.84	0.89	13.08
15-21	0	4.32	8.89
22-28	6.73	0	0
28-35	1.98	2.34	0.48
36-42	-	7.75	-

by higher densities, therefore, caused a complete suppression of shoot growth; whereas, lower densities reduced regrowth initiation only partly.

The overall pattern of stem initiation generally was similar in all treatments, although stem initiation was significantly delayed in direct proportion to larval density (Fig. 6). Once damage had ceased, stem density rapidly increased in all treatments to a peak at about 2 to 3 weeks after cutting. From this peak, stem density gradually declined until final harvest. Stem density in all treatments exceeded the minimal density of 375 stems/m^2 (Bula and Hintz 1978) needed for maximal yield. Even though delays in stem initiation produced large and significant reductions in stem density during the first 2 to 3 weeks following cutting, no consistently significant differences persisted after day 14 in 1981 and 1983, or day 21 in 1982. Larval damage, however, did significantly reduce peak stem density in 1982 and 1983, but not in 1981

Figure 6. Effect of stubble injury by various densities (larvae/0.1 m^2) of variegated cutworms on alfalfa stem density


1981
1982
1983
LARVAL DENSITY
0
1.5
3
6
9
12
STEMS/m2
DAYS AFTER CUTTING

(Table 10). The lack of effect in 1981 probably was caused by the increased plant vigor during the first production year (Smith 1975). The reduction in vigor between years also is evident in the mean stem density in all plots at final harvest (1683, 1040, and 750 stems/m^2 for 1981, 1982, and 1983, respectively). The reduction in peak stem density by larval defoliation may lessen a stand's ability to tolerate subsequent stresses.

Plant Development and Morphology

VCW damage had a substantial effect on mean stage of plant development (Table 11). Developmental differences, however, were not evident until day 14 in 1981 and 1983 and day 28 in 1982. In all samples after these dates, plant maturity decreased with increasing larval density. Maturation of plants in the 6, 9, and 12 larvae/0.1 m^2 treatments was delayed significantly in all years as compared with nondefoliated plants. The two largest densities, however, were not significantly different from each other during either year. Nondefoliated plants were more mature than plants in all other treatments on days 21 and 35 in 1981, but were not different from the 3 and 6 larvae/0.1 m^2 treatments on day 28 in that year. In 1982, nondefoliated plants were significantly more mature than plants in all other treatments on days 28 and 42, but were similar to plants in the 1.5 and 3 larvae/0.1 m^2 treatments on day 35. Except for one instance, plants in the 1.5 and 3 larvae/0.1 m^2 treatments were not significantly less mature than nondefoliated plants on any date in 1983. Consequently, the 1.5 and 3 larvae/0.1 m^2 densities caused some

Table 10. Effect of variegated cutworm feeding on peak and final stem density (#/m^2) of alfalfa

Larval density (No./0.1 m^2)	Peak density			Final density[a]		
	1981	1982	1983	1981	1982	1983
0	1681a	1234a	884a	1204a	705a	458ab
1.5	-	1176ab	765b	-	706a	428ab
3	1807a	1083bc	732b	1127a	670a	474a
6	1530a	1004cd	710b	1262a	708a	406b
9	1821a	893de	657b	1211a	607a	427ab
12	1576a	851e	-	1172a	634a	-

[a]Day 35 in 1981 and 1983, and day 42 in 1982.
Numbers followed by the same letter are not significantly different (P = .05); Duncan's Multiple Range Test.

delay in plant maturity, but the delay was not consistently significant in all years.

To more clearly demonstrate the effect of larval damage on plant development, the estimated number of days required to reach a particular stage of physiological development was determined. This was done by generating treatment-specific regressions of the percentage of stems with buds and flowers on time. The number of days to first bud and first flower was calculated from these equations. The mean number of additional days for first bud to occur was 3.0, 2.9, 5.4, 9.0, and 7.8 days for plants defoliated by densities of 1.5, 3, 6, 9, and 12 larvae/0.1 m^2,

Table 11. Effect of variegated cutworm stubble injury on mean developmental stage[a] of alfalfa on the last 3 sample times (days after cutting) in each year

Larval density ($No./0.1\ m^2$)	1981			1982			1983		
	21	28	35	28	35	42	21	28	35
0	1.25	1.54	2.32	1.17	1.83	2.45	1.30	1.99	2.92
1.5	-	-	-	1.03	1.70	2.16	1.20	1.81	2.90
3	1.16	1.54	1.83	1.06	1.64	2.10	1.18	1.94	2.89
6	1.07	1.41	1.46	1.01	1.55	1.90	1.03	1.63	2.69
9	1.01	1.04	1.21	1.01	1.13	1.66	1.00	1.56	2.43
12	1.02	1.18	1.50	1.00	1.10	1.47	-	-	-
Contrasts[b]									
0-6 vs 9-12	**	**	**	**	**	**	**	**	**
9 vs 12	NS	NS	NS	NS	NS	NS	-	-	-
0-3 vs 6	**	NS	**	**	NS	**	**	**	**
0-1.5 vs 3	**	NS	**	NS	NS	NS	NS	NS	NS
0 vs 1.5	-	-	-	**	NS	*	NS	**	NS

[a] 1 = vegetative, 2 = bud, 3 = flower.

[b] NS = not significant; * and ** are significant at the .05 and .01 levels, respectively.

respectively. Likewise, the mean number of extra days for first flower to occur was 0.8, 2.2, 4.7, 8.5, and 10.7 days, respectively. Typically, the delay caused by densities of 1.5 and 3 larvae/0.1 m^2 was not statistically significant for all years. Damage by higher larval densities did significantly delay maturity in most years.

VCW stubble feeding caused significant reductions in all stem-related variables, which include stem height, leaves per stem, and main-stem nodes per stem. The overall response of variables to specific treatment combinations was reflected in the whole plot portion of the ANOVA. Orthogonal contrasts C1 (0-6 vs. 9-12) and C3 (0-3 vs. 6) were highly significant ($P < .01$) in all years for all three variables. Contrast (C2) of the 9 and 12 larvae/0.1 m^2 treatments also was significant for all three variables in 1982, but this contrast was not significant for any variable in 1981. Contrasts C4 (0-1.5 vs. 3) and C5 (0 vs. 1.5) were not consistently significant in all years for any stem variable. Therefore, averaged across all dates, densities of 1.5 and 3 larvae/0.1 m^2 did not reduce height, nodes, or leaves per stem. Densities of 6 and greater larvae/0.1 m^2 significantly reduced all three stem-related variables.

The trends in stem variables also were apparent in the analysis of yield and leaf area index (LAI). Both variables increased linearly over time in all treatments (Figs. 7 and 8), but yield and LAI generally were suppressed significantly in all years only by densities of 6, 9, and 12 larvae/0.1 m^2. Neither variable, however, was significantly different between the 2 highest densities (contrast C2). Densities of 1.5 and

Figure 7. Effect of stubble injury by various densities (larvae/0.1 m^2) of variegated cutworms on alfalfa leaf area index

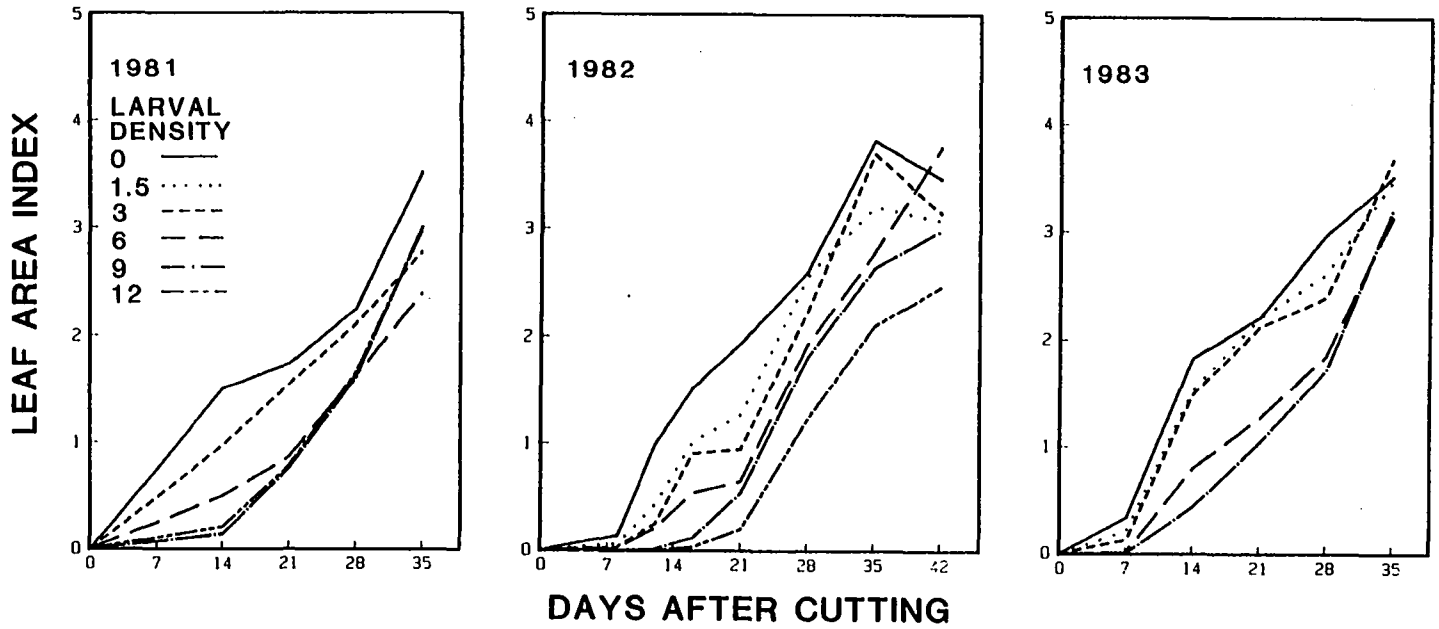
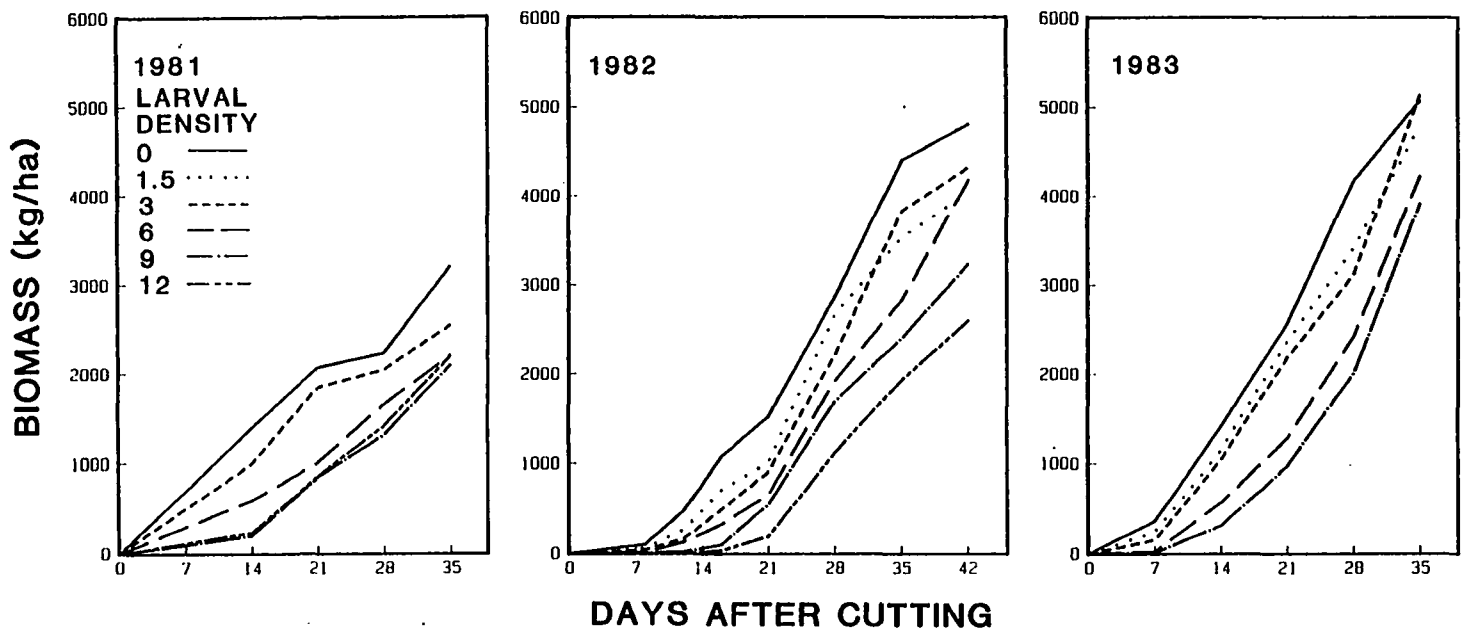

LEAF AREA INDEX
1981
LARVAL DENSITY
0
1.5
3
6
9
12
1982
1983
0
1
2
3
4
5
0
7
14
21
28
35
42
DAYS AFTER CUTTING

Figure 8. Effect of stubble injury by various densities (larvae/0.1 m^2) of variegated cutworms on alfalfa biomass


BIOMASS (kg/ha)
1981
LARVAL
DENSITY
0
1.5
3
6
9
12
1982
1983
DAYS AFTER CUTTING

3 larvae/0.2 m^2 (contrasts C4 and C5) significantly ($P < .05$) reduced yield in most years, but did not consistently reduce LAI.

Analysis of Growth Rates

Effects of VCW damage on the rate of increase of stem height, nodes per stem, and leaves per stem are shown in Table 12. Stem height accumulated at a significantly faster rate in 2 of 3 years in plants damaged by 9 and 12 larvae/0.1 m^2 as compared with healthy plants. Plants damaged by 9 larvae/0.1 m^2 produced stem height at a 77.6% and 29.6% faster rate than undamaged plants in 1981 and 1983, respectively. In 1982, the accumulation rate of stem height declined slightly in the highest density plots as compared with the check, but increased by 13% in plants damaged by 9 larvae/0.1 m^2. VCW defoliation had little effect on the rate of accumulation of mainstem nodes. Although contrast C1 was significant in 1982, nodes were produced at only an 8.4% faster rate in the 9 larvae/0.1 m^2 treatment as compared with the check. The difference between these two treatments in 1983 was +3.7% and no contrasts were significant in this year. Because there was little difference in the accumulation rates of nodes, the large increase in stem height accumulation rates most likely was attained by an increase in internode lengths in stems of severely defoliated plants.

The rate of accumulation of nodes per stem also has a bearing on the accumulation rate of leaves per stem. Leaf production rates declined with increasingly severe larval injury. Plants defoliated by 9 larvae/0.1 m^2 produced leaves at 49.1, 29.9, and 33.5% slower rates than

Table 12. Effect of variegated cutworm stubble injury on the daily accumulation rates of height (cm), main-stem nodes, and leaves per stem

Larval density (No./0.1 m^2)	Stem height			Nodes per stem[a]		Leaves per stem		
	1981	1982	1983	1982	1983	1981	1982	1983
0	.6601	1.4051	2.1200	0.3365	0.3743	1.871	2.235	2.997
1.5	-	1.4256	2.1799	0.3403	0.3741	-	1.933	2.714
3	.6291	1.4902	2.1556	0.3542	0.3791	1.441	1.906	2.786
6	.8730	1.5344	2.5603	0.3354	0.3854	1.126	1.679	2.505
9	1.1726	1.5880	2.7467	0.3649	0.3883	0.953	1.567	1.992
12	1.2983	1.3785	-	0.3670	-	1.073	1.262	-
Contrasts[b]								
0-6 vs 9-12	**	NS	**	**	NS	**	**	**
9 vs 12	NS	*	-	NS	-	NS	*	-
0-3 vs 6	NS	NS	**	NS	NS	**	**	NS
0-1.5 vs 3	NS	NS	NS	NS	NS	*	NS	NS
0 vs 1.5	-	NS	NS	NS	NS	-	*	NS

[a]Data not collected in 1981.

[b]NS = not significant, * and ** are significant at the .05 and .01 levels, respectively.

healthy plants in 1981, 1982, and 1983, respectively. These reductions resulted in highly significant C1 contrasts in all years and C3 contrasts in 1981 and 1982. The large reductions in leaf production rates, as compared with node production rates, suggest that there were fewer leaves per node. The cause of reduced production of leaves relative to nodes probably was a reduction in the development of axillary leaves and branches.

The effects of VCW stubble injury on subsequent growth rates of leaf (LGR), support-structure (SGR), and total (CGR) dry weight, and leaf area index (LAGR) are shown in Table 13. Leaf growth rate and SGR are the leaf and support components of yield, and LAGR is the rate of production of LAI. In 1981, CGR increased slightly and SGR decreased somewhat with treatment severity. No contrasts were significant for CGR and SGR in 1981. Leaf growth rate, however, increased significantly with larval density in 1981 such that LGR was 57% greater for plants damaged by 9 larvae/0.1 m^2 than for undamaged plants. In 1982 and 1983, both CGR and SGR declined with larval densities. These reductions were significant for densities of 9 and 12 larvae/0.1 m^2 in 1982 and densities of 6 and 9 larvae/0.1 m^2 in 1983. As in 1981, SGR was more adversely affected than CGR in both years. Treatments in both years had little effect on LGR, and except for contrast C5 in 1983, no contrasts were significant for LGR in 1982 and 1983.

Leaf area growth rate increased substantially with treatment severity in all years. Defoliation by 9 larvae/0.1 m^2 increased LAGR by 44.1, 43.8, and 53.9% in 1981, 1982, and 1983, respectively. Contrast C1 was significant in 1981 and 1983, and the C3 contrast was significant

Table 13. Effect of variegated cutworm stubble injury on crop growth rate (CGR), leaf growth rate (LGR), support growth rate (SGR), and leaf area growth rate (LAGR) of alfalfa[a]

Larval density ($No./0.1\ m^2$)	CGR			SGR			LGR			LAGR		
	1981	1982	1983	1981	1982	1983	1981	1982	1983	1981	1982	1983
0	7.97	17.91	14.32	5.13	11.65	9.46	2.84	6.26	4.86	0.093	0.110	0.084
1.5	-	15.98	11.94	-	9.79	7.72	-	6.19	4.22	-	0.118	0.090
3	6.90	17.90	14.13	4.15	10.67	9.81	2.75	6.23	4.32	0.085	0.151	0.098
6	7.91	13.82	12.29	4.13	8.02	7.05	3.68	5.81	5.24	0.092	0.127	0.109
9	8.78	12.62	10.87	4.32	6.78	6.05	4.46	5.83	4.82	0.134	0.139	0.129
12	9.20	10.48	-	5.15	5.30	-	4.05	5.18	-	0.131	0.115	-
Contrasts[b]												
0-6 vs 9-12	NS	**	*	NS	**	**	**	NS	NS	**	NS	*
9 vs 12	NS	NS	-	NS	NS	-	NS	NS	-	NS	NS	-
0-3 vs 6	NS	*	NS	NS	*	*	NS	NS	NS	NS	NS	NS
0-1.5 vs 3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
0 vs 1.5	-	NS	*	-	NS	*	-	NS	**	-	NS	NS

[a] CGR, LGR and SGR are in $gm/m^2/day$, and LAGR is in $m^2/m^2/day$.

[b] NS = not significant, and * and ** are significant at the .05 and .01 levels, respectively.

in 1982. The C1 contrast was not significant in 1982 because of a low LAGR in the highest density treatment.

Except for contrast C5 in 1983, contrasts comparing densities of 0, 1.5, and 3 larvae/0.1 m^2 were not significant for CGR, LGR, SGR, or LAGR. The comparison of these treatments with 6 larvae/0.1 m^2 also was usually not significant. Consequently, the subsequent CGR of alfalfa was significantly reduced by densities of 6 or greater larvae/0.1 m^2, i.e., by densities large enough to cause a complete regrowth delay. Almost all reduction in CGR was caused by a reduction in SGR, but LGR was not significantly reduced by any treatment. Interestingly, despite the lack of effect on LGR, LAGR was substantially greater in plants damaged by the highest larval densities.

Analysis of Partitioning Rates

It is clear from the previous analysis that a complete delay in regrowth changed the partitioning of resources during subsequent regrowth. Partitioning can be measured by the ratios of leaf area and leaf weight to total plant weight and by the ratio of leaf area to leaf weight. These ratios are the leaf area ratio (LAR), leaf weight ratio (LWR), and specific leaf area (SLA), respectively, where LAR = LWR × SLA (Hunt 1978).

Increases in larval density caused significant increases in LAR in all years (Table 14). The LAR of plants defoliated by 9 larvae/0.1 m^2 was 48.1, 40.5, and 63.5% greater than the LAR of nondefoliated plants during the three respective years. The increase in LAR was caused by a

Table 14. Effect of variegated cutworm stubble injury on alfalfa leaf area ratio (LAR), leaf weight ratio (LWR), and specific leaf area (SLA)[a]

Larval density (No./0.1 m^2)	LAR			LWR			SLA		
	1981	1982	1983	1981	1982	1983	1981	1982	1983
0	102.4	70.7	55.4	0.551	0.501	0.381	178	197	136
1.5	-	77.2	66.4	-	0.547	0.393	-	196	166
3	115.4	76.1	59.8	0.610	0.525	0.395	186	202	149
6	116.7	92.5	72.4	0.711	0.563	0.442	171	227	162
9	144.1	97.2	90.6	0.686	0.589	0.453	217	230	197
12	151.6	99.3	-	0.676	0.622	-	211	222	-
Contrasts[b]									
0-6 vs 9-12	**	**	**	**	**	**	*	**	**
9 vs 12	NS	NS	-	NS	NS	-	NS	NS	-
0-3 vs 6	**	*	**	NS	**	**	NS	**	NS
0-1.5 vs 3	NS	NS	NS	NS	NS	NS	NS	NS	NS
0 vs 1.5	-	NS	NS	-	NS	*	-	NS	**

[a] LAR (cm^2/gm), LWR (gm/gm), and SLA (cm^2/gm).

[b] NS = not significant; * and ** are significant at the .05 and .01 levels, respectively.

combination of an increase in both LWR and SLA. Nine larvae/0.1 m^2 caused LWR to increase by 22.0, 24.2, and 18.6% and SLA to increase by 18.7, 15.2, and 45.5% as compared with nondefoliated plants during the three years, respectively. Orthogonal treatment contrasts, however, indicated that densities of up to 3 larvae/0.1 m^2 usually did not significantly affect plant partitioning. Densities of 6 larvae/0.1 m^2 did alter partitioning significantly in most years, and densities greater than 6 larvae 0.1 m^2 increased all three partition variables significantly in all years.

Consequently, densities capable of completely delaying regrowth increased the allocation of leaf area per unit of dry weight by increasing the ratio of leaf weight per unit of total weight, and by increasing the leaf area per unit of leaf weight. The latter consequence was accomplished by producing thinner, less-dense leaves. Increased LWR could be the result of the production of larger leaves or more leaves per unit of total weight. Calculation of the ratio of leaf number per unit of total weight (LNR) showed that LNR was not significantly affected by VCW damage in 1982 and 1983 (Table 15). Leaf number ratio, however, declined significantly in 1981. Calculation of the ratio of area and weight per leaf showed that both variables increased significantly in all years for densities of 6 or greater larvae/0.1 m^2. Furthermore, leaf area responded to a greater extent than leaf weight, which is indicative of the increase in SLA. The increase in LWR, therefore, was not accomplished by the production of more leaves; rather it was the result of the production of larger leaves.

Table 15. Effect of variegated cutworm stubble injury in alfalfa leaf number ratio (LNR), and area (cm^2) and weight (mg) per leaf

Larval density (No./0.1 m^2)	LNR			Leaf weight			Area/leaf		
	1981	1982	1983	1981	1982	1983	1981	1982	1983
0	185.0	51.1	58.9	2.36	6.88	6.34	0.53	1.34	0.93
1.5	-	49.8	60.6	-	7.78	6.50	-	1.55	1.10
3	160.4	47.3	59.7	3.10	7.81	6.75	0.66	1.57	1.00
6	154.8	48.7	55.2	4.34	8.13	8.05	0.76	1.84	1.33
9	124.7	50.6	53.6	5.63	8.30	8.32	1.20	1.92	1.69
12	110.2	54.0	-	5.88	8.24	-	1.31	1.82	-
Contrasts[a,b]									
0-6 vs 9-12	**	NS	NS	**	NS	**	**	**	**
0-3 vs 6	NS	NS	NS	**	NS	*	*	**	*

[a]NS = not significant; * and ** are significant at the .05 and .01 levels, respectively.

[b]Contrasts C2, C4, and C5 were not significant in any year.

DISCUSSION

Comparison of the partitioning variables with the component growth rates suggests that the apparent increase in resource partitioning to leaf weight was only a relative increase. In fact, the accumulation rate of leaf weight generally remained unchanged, whereas the support component of CGR declined substantially. Therefore, the change in partitioning was actually a reduction in support weight relative to leaf weight, and not an increase in leaf weight, per se. The increase in SLA did add to the reduction of support weight so that the increase in LAR was caused by a combination of a reduction in support weight and an increase in the leaf area per unit of leaf weight. The increase in SLA (i.e., reduced leaf density) would have the effect of enhancing the area available for incident light interception without a concomitant increase in leaf biomass. The relative differences in growth and partitioning rates between 1981 and the later years probably were the result of the moisture stress that occurred in 1981.

The changes in plant partitioning may be the consequence of an alteration in carbohydrate source-sink relationships in damaged plants. Although current photosynthesis may be available during initial regrowth, plants normally use carbohydrates stored in the roots as the primary source of carbon for about the first three weeks of regrowth (Hodgkinson 1969, Pearce et al. 1969, Smith and Marten 1970). New leaves, however, import and use translocated carbohydrates only during the first week or so of regrowth, after which they become self-sufficient. Support structures, on the other hand, continue to rely on

stored carbohydrates for about three weeks or until reserves are depleted (Hodgkinson 1969).

In plants injured enough to delay regrowth for 10 to 14 days (i.e., densities of 6 or greater larvae/0.1 m^2), subsequent regrowth would occur without the benefit of large reserves of stored carbohydrates. These reserves presumably would already be near depletion at the time larval defoliation ceased. Consequently, regrowth would need to rely primarily on photosynthates produced by current leaf photosynthesis. Leaf growth probably would not be suppressed greatly, because assimilate sources tend to satisfy their own needs before exporting assimilates (Cook and Evans 1978). Growth of support structures (carbohydrate sinks) most likely would be suppressed more severely, because of the loss of stored carbohydrates and the inability of current photosynthesis to make up the difference.

Therefore, in conclusion, subsequent growth and partitioning of alfalfa were significantly affected when VCW stubble injury was severe enough to cause a complete delay in regrowth. Changes in partitioning by completely delayed plants, however, seemed to minimize the adverse effects of stubble injury by maintaining the growth rate of the primary photosynthetic organs (e.g., leaves) at the expense of support structure growth.

PART IV. DEVELOPMENT OF ECONOMIC INJURY LEVELS AND MANAGEMENT PRACTICES FOR THE VARIEGATED CUTWORM IN ALFALFA

ABSTRACT

Studies were conducted to investigate the impact of the duration and intensity of stubble injury by the variegated cutworm (VCW), Peridroma saucia (Hübner), on the yield, quality, and economic return of alfalfa. One study assessed the effects on alfalfa productivity of the duration of complete regrowth suppression by simulated insect injury. The intensity of damage was investigated in the second study where the effects on alfalfa regrowth of various densities of last-stage larvae were examined. Larval feeding occurred for 10 to 15 days. Regrowth was suppressed completely by 6 and greater larvae/0.1 m^2, whereas densities of 1.5 and 3 larvae/0.1 m^2 only partly suppressed regrowth. Stubble injury in both studies affected regrowth through: (1) an initial loss in plant regrowth with a concomitant delay in plant development and loss in dry matter, and (2) an additional loss of dry matter associated with a reduction in subsequent growth rates. Production of dry matter, therefore, was affected more adversely than plant development. Herbage quality was affected primarily by the relative delay in plant maturity. Consequently, dry matter and nutrient yields were reduced at the same stage of plant development. These results, however, were significant only when regrowth was completely suppressed for more than 3 days. Likewise, plant development and yield were significantly affected only by larval densities of 6 and greater larvae/0.1 m^2. Lower densities did not consistently affect regrowth significantly in all years.

A replacement feed-cost analysis was conducted for both studies. Dollar-loss equations were generated for harvest systems where cutting

is based on plant developmental stage (i.e., first bloom) or calendar date. Regrowth-delay loss thresholds and VCW economic injury levels were calculated for both harvest systems, and a management program for VCW in alfalfa stubble developed.

INTRODUCTION

Alfalfa is attacked by a large number of defoliators. Although cutting is often an effective method of control, stubble feeding by a small number of surviving individuals may cause substantial damage to new regrowth. The two defoliators most often associated with regrowth damage are the variegated cutworm (VCW), Peridroma saucia (Hübner), and the alfalfa weevil (AW), Hypera postica Gyllenhal (Fick 1976, USDA 1957-1975). A number of other species also have been reported to damage alfalfa regrowth, including the armyworm, Pseudoletia unipuncta (Haworth), dingy cutworm, Feltia subgothica (Haworth), darksided cutworm, Euxoa messoria (Harris), and bristly cutworm, Mamestra regina (Stephens) (USDA 1957-1975, USDA 1976-1981, Walkden 1950).

VCW phenology in Iowa is such that first generation larval development coincides with the first growth cycle of alfalfa. Typically, most larvae are at or the near the beginning of the last larval stage (6) at the first cutting in early June. Stubble damage usually occurs after the first cutting, but regrowth injury after the second cutting also has been reported (USDA 1975). Partial to complete suppression of regrowth may occur for several days to two weeks or more (Soteres et al. 1984, USDA 1957-1975). Based on numbers of reports in the Coop. Economic Insect Report and Coop. Plant Pest Report, regrowth delays by VCW primarily are a problem in the southern and central Great Plains from north Texas, Oklahoma, and Arkansas to South Dakota, Iowa, and southern Minnesota. Widespread outbreaks occurred in 1957, 1964, 1968, 1973, 1975, and 1977, with localized outbreaks being reported in six additional years.

Regrowth damage by AW primarily is a problem in the northern US. In this area, AW overwinters mainly in the adult stage, and larval populations usually reach a peak about the time of the first cutting. Feeding by surviving larvae may cause considerable damage to new regrowth for up to two weeks (Hamlin et al. 1949). Newly emerged adults also may suppress new regrowth (Bjork and Davis 1984).

The response of alfalfa to insect stubble injury has received little attention, and no studies have specifically examined stubble damage by VCW. Some studies (Liu and Fick 1975, Fick 1976), however, have investigated stubble injury by AW. Although AW may significantly reduce first-cutting yield (Hintz et al. 1976), a study in New York found that AW significantly reduced yield only during the second cutting of a three-cut system (Liu and Fick 1975). Larvae continued to feed on stubble after the first cutting for 5 to 15 days, which resulted in a second growth yield loss of 31% and a seasonal loss of 17%. In a companion study (Fick 1976), yield losses caused by stubble damage increased linearly with larval density up to ca. 1600 larvae/m^2. Greater densities did not cause additional significant losses, and maximal yield loss represented approximately 1/3 of the potential yield of a 40-day second growth period. Herbage of defoliated plants was less mature, shorter in height, and lesser in dry weight than nondefoliated plants. Leaf percentage and forage quality, however, were greater in defoliated plants. Most of these differences were attributed to the relative difference in herbage age and developmental stage at harvest.

Presented here are the results of two studies, in which the impact of actual and simulated stubble injury by VCW on the yield, quality, and

economic return of alfalfa is assessed. Studies focused on VCW because little is known about the effects of stubble feeding by this insect on alfalfa. Specific objectives were to determine: (1) how long a complete suppression of regrowth could be tolerated before significant economic losses occurred, (2) the number of larvae required to completely suppress alfalfa regrowth, and (3) the effects of partial and complete regrowth suppression by VCW on alfalfa productivity. Using this information, economic injury levels and management practices for VCW were developed, and guidelines for the management of AW also are proposed.

MATERIALS AND METHODS

Both studies were conducted in a field of 'Valor' alfalfa located 2.5 km south of Ames, Iowa on a Webster silty-clay loam. Alfalfa seed was drill-planted in 17.5-cm rows at the rate of 13.5 kg/ha on 20 August, 1980. Recommended management practices typical of central Iowa were followed, including the top-dress application of phosphorous and potassium during the spring of each year. Plot areas were treated with malathion at the rate of 1.1 kg (AI)/ha to suppress AW during the first growth cycle. Plots also were sprayed with malathion at the same rate after the 21-day sample date to control the potato leafhopper, Empoasca fabae (Harris).

Delay of Regrowth Study

A study was conducted to assess the effects of complete regrowth suppression for varying periods of time on alfalfa production. Insect damage sufficient to cause a complete suppression of regrowth was simulated by hand-picking all new regrowth (leaves and stems) at the point of attachment to the stubble or soil surface. Shoots were picked every two days beginning on day 1 (24 h after cutting) until the desired duration of damage was achieved. Treatment durations were 0 (unpicked), 1, 3, 7, and 11 days in all trials. The study was conducted four times; once during the second and third growth cycles in 1981 and 1982. Trials were begun on 1 June and 30 June in 1981 and 1 June and 14 July in 1982. The experimental area was clipped on these dates to a stubble height of 7.5 cm, and all plots were established within 12 h of cutting.

A split-plot experimental design was used, with whole plots consisting of the duration of regrowth delay and subplots being sample times. Whole plots, measuring 1.5 m (7 rows) by 3 m, were arranged in a randomized complete-block design with four replications during the first trial in 1981, and five replications in the other trials. Whole plots were divided in to six subplots measuring 0.36 (2 rows) by 1.0 m. Subplots were sampled weekly for six weeks beginning on day 7 after cutting during all trials, except during the first trial in 1981 when the last two samples were not taken. Subplots were harvested with hand clippers by clipping all above-ground herbage. Stem density was determined on all sample dates in 1982 and on the final sample dates in the 1981 trials. A representative subsample of 25 stems was collected from each sample to monitor plant development. Stems were classified by vegetative, bud, flower, or pod stage. The date of first bloom was estimated for each treatment and trial by solving a linear or quadratic (whichever described the data best) regression equation of percentage of flowering stems against time.

All samples were dried in a forced-air oven at 70°C for 72 h before dry weight was measured. Quality measurements were made on those samples collected on sample dates 21 through 42 during all trials. Samples first were ground through a 1-mm mesh screen using a Wiley mill. Quality was evaluated by determining herbage digestibility and crude protein content (CP). A micro-Kjeldahl technique was used to determine CP. Digestibility was assessed with the Tilley-Terry _in vitro_ digestible dry matter (IVDDM) assay as modified by Marten and Barnes (1979) for direct acidification. CP and IVDDM of all samples were based on duplicate

determinations. Quality measurements were coupled with dry weight measurements to calculate estimated yields of CP and digestible dry matter (DDM).

Statistical analyses

CP, IVDDM, and yield of CP and DDM were analyzed by date and trial with an analysis-of-variance (ANOVA) and orthogonal treatment contrasts. Treatment (regrowth delay) contrasts were C1 = 0-3 versus 7-11, C2 = 7 versus 11, C3 = 0-1 versus 3, and C4 = 0 versus 1. Well-managed alfalfa, however, normally is harvested based on stage of physiological development rather than calender date (Smith 1975). Consequently, yield and quality measurements also were calculated for the same stage of development. First bloom was chosen because it is easily identifiable in the field and it represents a reasonable compromise between yield and quality (Hanson and Barnes 1973, Smith 1975). First bloom estimates of herbage yield and quality were generated by fitting treatment-specific regression equations to the observed data for each trial. The equations then were solved for the previously calculated date of first bloom. Trial 1 in 1981 was not included in this analysis because there were not enough sample dates for generating regression equations. Yield and quality estimates calculated for the other three trials were analyzed with an ANOVA and orthogonal treatment contrasts using trials as replicates.

Larval Infestation Study

The effects of stubble feeding by various densities of VCW larvae on the second growth cycle of alfalfa were assessed in a study using barriered plots. Plots, measuring 1.5 m (7 rows) by 4 m, were established immediately after the first cutting on 10 June, 1981, 1 June, 1982, and 14 June, 1983. Plots were clipped to a stubble height of 7.5 cm with a mower/conditioner. Employing a technique used by Showers et al. (1983), each plot was enclosed with a 45-cm high aluminum barrier. All barriers were in place within 36 h of cutting, and plots were infested with early ultimate-stage larvae at dusk. Larvae for all studies were progeny of feral adults collected during the spring of each year. Larval rearing procedures are described in Part III of this dissertation.

A split-plot experimental design was employed with whole plots consisting of larval density. Whole plots were arranged in a randomized complete-block design with five blocks in 1981 and 1982, and four blocks in 1983. Larval densities in all years were 0, 1.5, 3, 6, 9, and 12 larvae/0.1 m^2, except in 1981 and 1983 when the 1.5 and 12 larvae/0.1 m^2 densities were not used, respectively. Whole plots in the first two years were divided into four subplots measuring 0.36 (2 rows) by 1.5 m. After larval feeding ceased, one subplot was sampled weekly beginning on day 14 in 1981 and day 21 in 1982. Subplots were harvested by clipping all above-ground herbage with hand clippers. Dead stems and trash were separated from the alfalfa herbage, and stem density and dry weight measured. A subsample of 25 stems was taken from each sample in

both years to determine mean stage of plant development and percentage of flowering stems.

In 1983, the arrangement of subplots was modified to specifically examine the possible interaction between stubble damage by VCW and subsequent week populations. Whole plots were divided into three 1.0 m^2 subplots. Two subplots were hand-weeded on day 21, and weeds were allowed to develop in the third subplot. Alfalfa regrowth was monitored weekly for five weeks beginning on day 7 in one of the weeded subplots. A representative sample of 25 stems was collected to measure shoot dry weight, mean stage of plant development, and percentage of flowering stems. Stem density was nondestructively determined in a randomly chosen half of the other weeded subplot. Weekly yield estimates were calculated from shoot weight and density, and final yield was measured directly on day 35 by harvesting the nondestructively sampled subplot.

Samples in all years were processed and quality measurements were determined as previously described in the regrowth delay study for herbage collected on days 14-35 in 1981, days 21-42, in 1982 and days 21-35 in 1982. Yields of CP and DDM were calculated from these determinations.

Statistical analyses

Yield and quality measurements were analyzed by sample date within year with an ANOVA, and treatment (larval density) differences were elucidated with Duncan's Multiple Range Test. Date of first bloom was estimated for each plot within a year by linear interpolation of the percentage of flowering shoots. CP, IVDDM, and nutrient and dry matter

yield at first bloom also were estimated as described in the regrowth delay study. Estimates were calculated for each plot, and these results were analyzed with an ANOVA and Duncan's Multiple Range Test.

Economic Analysis

Dollar value return estimates were calculated for both studies using a modified replacement feed-cost analysis (Craven and Hasbargen 1979, Onstad and Shoemaker 1984). The analysis uses CP and DDM yields to estimate the dollar value return of hay production. Previous analyses, however, have based replacement costs on the value of corn-soybean meal. This practice probably has overestimated the value of hay because corn and soybean meal generally is a more valuable feedstuff than alfalfa hay. Furthermore, the loss in hay yield most likely will be replaced with more hay rather than corn and soybean meal. Consequently, dollar values in the present analysis were based on the market values of hay purchased on-farm and hay bought off-farm. Prices of $61/MT ($55/Ton) and $77/MT ($70/Ton), respectively, are representative of the current market value in Iowa of aftermath hay cut at or before first bloom. The price differential between hay types is the result of transportation costs for off-farm hay.

Dollar value estimates were calculated based on the yield of CP and DDM and the unit value of each nutrient. Before dollar values were calculated, however, dry matter and nutrient yields were adjusted to reflect the harvest loss normally associated with curing and baling of hay. This was necessary because commodity prices were based on baled

hay, whereas yields were based on the standing crop before it is cut. Hoglund (1964) reported average harvest losses of 25% for curing and baling alfalfa, thus, all yield values were reduced by this amount.

Unit values of CP and DDM were calculated by dividing the market price of hay, expressed on a dry matter basis, by the average CP and DDM content of aftermath hay cut at first bloom. The National Research Council (1969) reports average nutrient contents for this type of hay (feedstuff reference No. 1-00-059) as 57% total digestible nutrients (estimated by IVDDM) and 18.4% CP. The resulting unit costs are $0.1230 and $0.1565/kg for DDM and $0.3847 and $0.4934/kg for CP when hay is valued at $61 and $77 per MT, respectively. After separate dollar values were generated based on CP and DDM yields, an overall value per ha was calculated as the average of the two estimates.

Dollar returns and dollar loss equations for both studies were calculated for harvest systems where either plant developmental stage or calendar date would be used as the criterion for cutting. Dollar values for first bloom were used for the developmental-stage harvest system. Values for the calendar date system were taken from sample dates when the undamaged plants were near first bloom. Sample dates used for this system were day 28 for all trials in the delay of regrowth study, and day 28 in 1981 and day 35 in 1982 and 1983 for the larval infestation study.

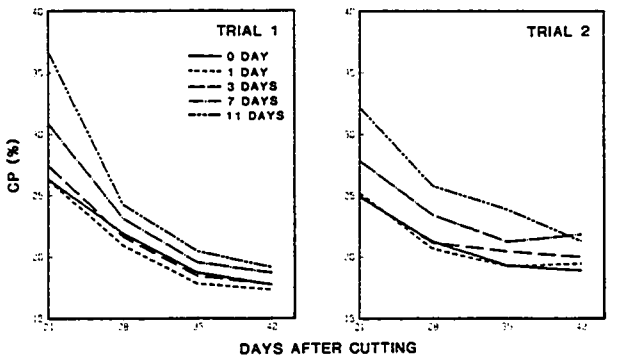
RESULTS

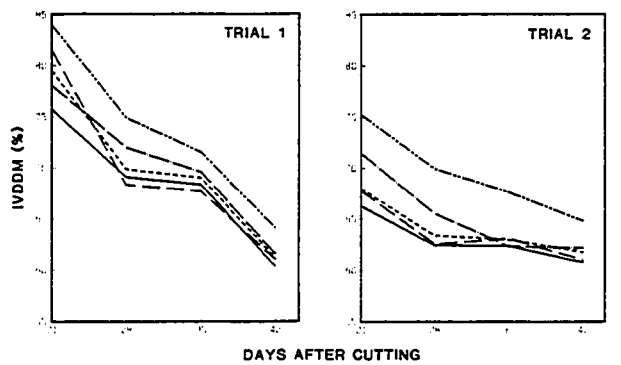
Delay of Regrowth Study

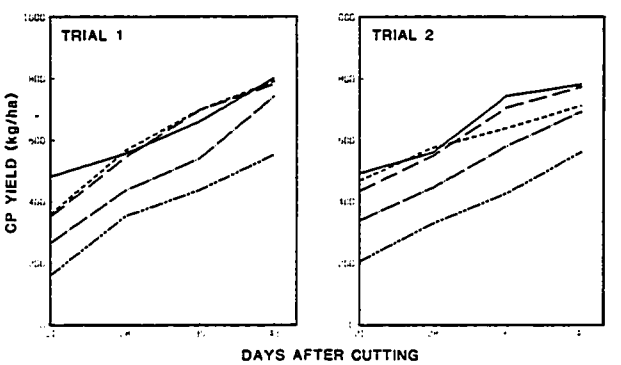
Results of the analysis of plant development indicate that first bloom occurred 26.3, 26.6, 27.5, 29.7, and 34.7 days after cutting, when averaged for all trials, for undamaged plants and plants delayed for 1, 3, 7, and 11 days, respectively. Regrowth delays of 1 and 3 days did not significantly ($P > .05$) increase the number of days to first bloom, whereas delays of 7 and 11 days caused significant ($F_{1,12} = 35.06$, $P < .01$) increases in days to first bloom. Furthermore, plants damaged for 11 days were delayed for a significantly ($F_{1,12} = 12.11$, $P < .01$) longer time than 7-day damaged plants. First bloom, however, was delayed less than expected based on the actual duration of damage. Plants delayed for 1, 3, 7, and 11 days required an additional 0.22, 1.15, 3.41, and 8.46 days for first bloom to occur, respectively. Therefore, a 3-day regrowth delay caused only a 1-day delay in date of bloom, and plants delayed for 7 and 11 days reached first bloom approximately 3 days sooner than expected, based on the initial regrowth delay.

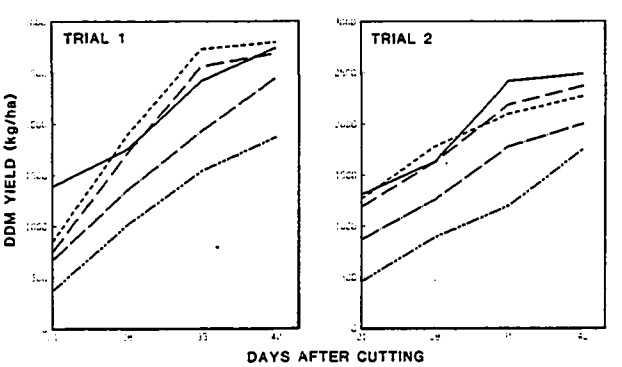
Regrowth delays also significantly affected forage quality and nutrient yields (Fig. 9). On any given sample date, CP and IVDDM increased with longer regrowth delays. This increase was significant ($P < .05$) on all sample dates and trials for plants delayed for 7 and 11 days (contrast C1). Delays of 1 and 3 days did not significantly affect either quality parameter on any date in all trials. Forage quality declined somewhat more quickly in severely delayed plants, as compared with undamaged plants. This observation, however, probably is an artifact

Figure 9. Response of alfalfa crude protein (CP), in vitro digestible dry matter (IVDDM), CP yield, and digestible dry matter (DDM) yield to complete regrowth suppression for various times (days) in 1982 (1981 data not shown)


TRIAL 1
TRIAL 2
0 DAY
1 DAY
3 DAYS
7 DAYS
11 DAYS
CP (%)
DAYS AFTER CUTTING


TRIAL 1
TRIAL 2
IVDDM (%)
DAYS AFTER CUTTING


TRIAL 1
TRIAL 2
CP YIELD (kg/ha)
DAYS AFTER CUTTING


TRIAL 1
TRIAL 2
DDM YIELD (kg/ha)
DAYS AFTER CUTTING

of the relative herbage age in each of the treatments, in that the rate of decline of herbage quality moderated as herbage became older. Although damaged plants had significantly better herbage quality, yields of CP and DDM were reduced significantly when regrowth was delayed for 11 days, and to a lesser extent, 7 days (Fig. 9). Except in one instance (day 21, trial 1, 1982), delays of 1 and 3 days did not significantly reduce CP and DDM yields, when compared with undamaged plants, on any sample date in all trials.

These results demonstrate that alfalfa quality and nutrient yields are affected by regrowth delays of greater than 3 days. Yield and quality differences, however, may be caused entirely by the relative differences in herbage age and maturity. The confounding effect of regrowth age was removed by calculating quality and nutrient yields for the same stage of development (i.e., first bloom) (Table 16). Although CP and IVDDM were somewhat greater in plants delayed for 7 and 11 days, the increase was relatively small and significant only for IVDDM (contrast C1). No other contrasts were significant for IVDDM, and no contrasts were significant for CP. Conversely, delays of greater than 3 days did cause significant reductions in dry matter (DM), DDM and CP yield at first bloom. Yields were not significantly affected by delays of 1 and 3 days. Therefore, regrowth delays of 7 and 11 days had a more severe effect on DM production than plant development and quality. Yield reductions were caused by a combination of the direct initial loss of DM and a reduction in the subsequent crop growth rate of the regrowth (Part II of this dissertation).

Table 16. Effect of regrowth delays on alfalfa crude protein (CP), in vitro digestible dry matter (IVDDM), dry matter (DM) yield, digestable dry matter (DDM) yield, and CP yield, and dollar-value returns for calendar date and first bloom harvest systems[a]

Regrowth delay (days)	Quality (%)		Yield (kg/ha)			Dollar value/ha			
						First bloom		Calendar date	
	CP	IVDDM	DM	DDM	CP	$61/MT	$77/MT	$61/MT	$77/MT
0	21.92	67.20	2586	1709	542	157.60	200.55	167.77	213.49
1	21.94	67.53	2581	1784	556	162.86	207.23	171.36	218.05
3	22.19	67.20	2551	1684	538	155.59	197.99	155.54	197.92
7	23.80	68.67	2093	1382	459	130.41	165.95	128.95	164.08
11	23.13	68.19	2003	1352	440	126.31	160.73	99.37	126.39
Contrasts[b]									
0-3 vs 7-11	NS	*	**	**	**	**	**	**	**
7 vs 11	NS	NS	NS	NS	NS	NS	NS	**	**

[a]Trial 1 in 1981 not included in analysis.

[b]Contrasts comparing delays of 0, 1, and 3 days were not significant (NS) for any variable; * and ** indicate significance at the .05 and .01 levels, respectively.

Economic analysis

Reductions in nutrient yields for harvest systems based on first bloom and calendar date translated into significant losses in dollar value returns per ha (Table 16). Values at first bloom declined significantly for both commodity prices in treatments delayed for more than 3 days, when compared with returns of treatments damaged for 1 and 3 days. The additional delay from 7 to 11 days did not produce additional significant dollar-value reductions. The same results were true for calendar-date values, except that the dollar values were significantly different for 7 and 11 day delays. Delays of 1 and 3 days did not significantly affect dollar returns, as compared with undamaged plants, for either harvest system.

A delay-loss threshold (point where the loss caused by a regrowth delay would justify the cost of insect control) was generated using the estimates of dollar returns by calculating the dollar loss associated with each treatment as the difference in value from the undamaged treatment. Loss values were regressed against the days delay in regrowth, forcing the regression through the origin, to calculate the dollar loss per ha for each day delay in regrowth. Loss equations were developed for both harvest systems. For a system where harvest occurs at first bloom, each day delay caused $2.97 and $3.78 loss per ha when hay is valued at $61 and $77 per MT, respectively. These values translate into delay-loss thresholds of 4.4 to 7.5 days (Table 17). Dollar losses for a calendar-date harvest system were $5.21 and $6.57/ha for each day delay when hay costs $61 and $77/MT, respectively. The calculated delay-loss thresholds for this system ranged from 2.6 to 4.3 days (Table 17).

Table 17. Delay-loss thresholds (days) and VCW economic injury levels (larvae/0.1 m^2) for alfalfa stubble, based on calendar-date and plant-stage (first bloom) harvest systems

Commodity price ($/MT)	Plant-stage harvest		Calendar-date harvest	
	Control costs[a]		Control costs	
	$16.80	$22.40	$16.80	$22.40
	Delay-loss thresholds			
61	5.7	7.5	3.2	4.3
77	4.4	5.9	2.6	3.5
	VCW economic injury levels			
61	3.6	4.8	2.1	2.8
77	2.8	3.8	1.7	2.2

[a]Control costs ($/ha) are based on a ground application of 1.1 kg (MI)/ha of trichlorfon (Dylox 80w), plus $6.18 and $12.35/ha for application costs.

Larval Infestation Study

Larval damage occurred for 10 to 12 days in 1981 and 1983, and for about 15 days in 1982. Densities of 9 and 12 larvae/0.1 m^2 consistently caused complete delays in regrowth in all years. Feeding by 1.5 and 3 larvae/0.1 m^2 did not completely suppress regrowth in any year. Damage, however, was evident on most shoots with leaves and leaflets often being completely removed. Six larvae/0.1 m^2 completely suppressed regrowth in some plots, whereas regrowth was only partly suppressed in other plots. Shoots that did grow in these plots usually were severely stunted, and most leaves were absent.

Larval feeding caused delays in plant development, as measured by days in first bloom, that were proportional to larval density (Table 18). The mean (averaged across years) number of extra days to first bloom was 0.8, 2.2, 4.7, 8.5, and 10.7 days for densities of 1.5, 3, 6, 9, and 12 larvae/0.1 m^2, respectively. In most years, delays caused by 1.5 and 3 larvae/0.1 m^2 were not statistically significant. Damage by higher densities delayed first bloom significantly in most years.

The effects of VCW stubble feeding on forage quality and nutrient yields are shown in Fig. 10. CP and forage digestibility declined in all treatments with time. The relative differences between treatments in forage quality also were similar on most sample dates. Forage quality almost always was greater in the 6, 9, and 12 larvae/0.1 m^2 treatments than in the lower density treatments. In most instances, forage quality was significantly ($P < .05$) different in the 9 and 12 larvae/0.1 m^2 treatments in 1982, but not in 1981. Comparisons of the 0, 1.5, and 3 larvae/0.1 m^2 treatments usually were not significant ($P > .05$) on most sample dates for CP and IVDDM.

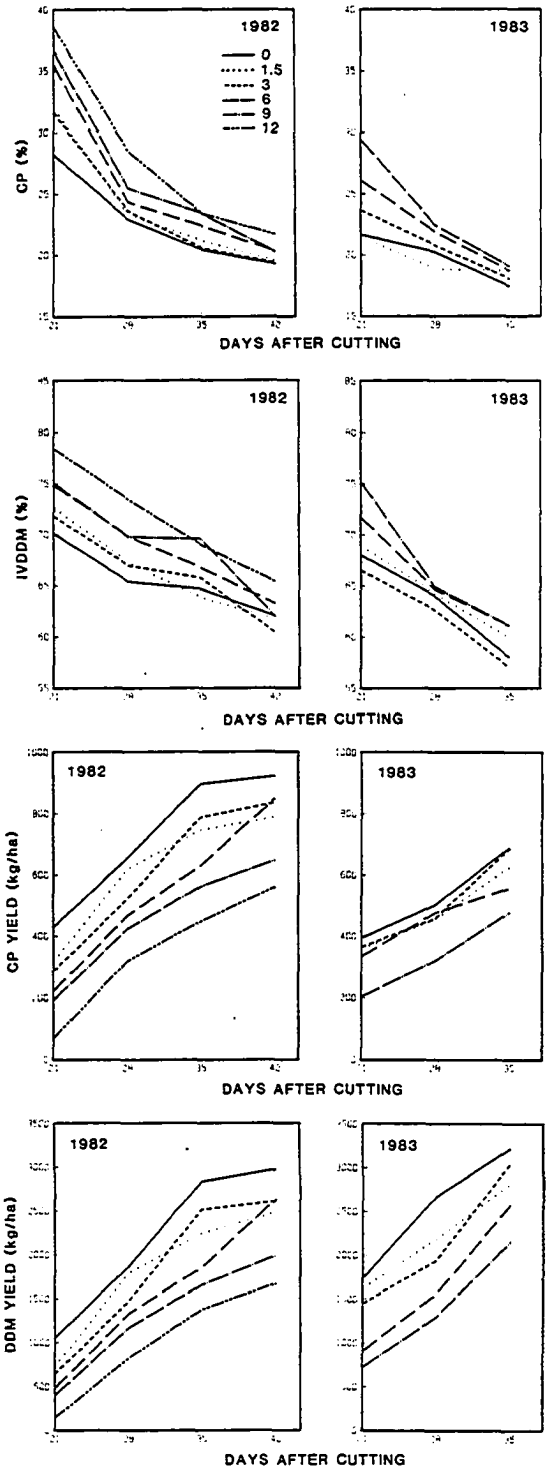
The increase in forage quality with larval density was not enough to prevent significant reductions in nutrient (CP and DDM) yields (Fig. 10). Larval defoliation produced similar, significant reductions in CP and DDM yields on all sample dates in all years. Densities of 6, 9, and 12 larvae/0.1 m^2 significantly ($P < .05$) reduced nutrient yields on nearly all sample dates, when compared with lower density treatments. Nutrient yields were not significantly ($P > .05$) different in the 9 and 12 larvae/0.1 m^2 treatments on any date in 1981 and 1982, except on day 21 in 1982. Additionally, there were no consistently significant

Table 18. Effects of various densities of variegated cutworms on days to first bloom and on crude protein (CP), in vitro digestible dry matter (IVDDM), yield of dry matter (DM), digestible dry matter (DDM), and CP at first bloom[a]

Year	Larvae per $0.1\ m^2$	Days to first bloom	Quality (%)		Yield (kg/ha)		
			CP	IVDDM	DM	DDM	CP
1981	0	23.8a	24.10a	68.95a	2171a	1492a	535ab
	3	29.2b	23.88a	66.02ab	2182a	1463a	542ab
	6	31.0b	24.61a	66.03ab	1872a	1237a	468b
	9	38.5c	24.69a	64.18b	2344a	1504a	586a
	12	35.7c	25.27a	64.83ab	2205a	1427a	559ab
1982	0	35.3a	21.13a	64.10a	4017a	2554a	821a
	1.5	37.3a	21.64a	64.17a	3408b	2297ab	755ab
	3	37.7ab	20.84a	63.05a	3784ab	2309ab	748ab
	6	39.8b	20.23a	64.04a	3698ab	2385ab	782ab
	9	43.3c	17.72b	62.32a	3438b	2174ab	704ab
	12	44.8c	17.57b	63.52a	2888c	1966b	651b
1983	0	25.8ab	20.33a	65.01a	2626a	1635a	506a
	1.5	27.0ab	19.71a	65.12a	2366ab	1543ab	471ab
	3	25.0a	21.99b	64.30a	2152bc	1295bc	441ab
	6	28.3ab	22.09b	65.63a	1976bc	1221c	396b
	9	28.6b	23.31c	66.60a	1658c	1034c	346c

[a]Means followed by the same letter are not significantly (P = .05) different; Duncan's Multiple Range Test.

Figure 10. Response of alfalfa crude protein (CP), in vitro digestible dry matter (IVDDM), CP yield and digestible dry matter (DDM) yield to stubble injury by various densities (larvae/0.1 m^2) of variegated cutworms in 1982 and 1983 (1981 data not shown)


1982
1983
0
1.5
3
6
9
12
CP (%)
IVDDM (%)
CP YIELD (kg/ha)
DDM YIELD (kg/ha)
DAYS AFTER CUTTING

($P > .05$) differences in nutrient yields between treatments with 3 or less larvae/0.1 m^2 in any year. Consequently, on any particular sample date, larval damage increased forage quality, but reduced nutrient yields in direct proportion with larval density. These effects, however, generally were significant only for densities of 6 or greater larvae/0.1 m^2. Lower densities did not consistently affect forage quality or nutrient yields significantly.

Larval damage had variable effects on forage quality at first bloom (Table 18). Although IVDDM tended to decline with increasing densities, there were no strong and significant trends in forage quality at first bloom in 1981. IVDDM was not significantly different between treatments in 1982 and 1983. CP levels declined significantly with larval densities in 1982, but increased significantly with larval densities in 1983. Thus, there were no strong and consistent trends in either measure of quality at first bloom when all three years are considered. This result and the similar trends in quality in all treatments over time suggest that most of the differences in quality on a particular sample date were caused by differences in relative herbage age. There was little evidence of an additional affect on forage quality, exclusive of the effect on herbage age, as a result of larval stubble damage.

There also were no consistently significant trends in dry matter and nutrient yields at first bloom in 1981. The lack of effect on DM production in 1981 probably was the result of moisture conditions during this trial. Moisture stress during the first 3.5 weeks of the study suppressed growth rates in all treatments. When it did rain, undamaged plants and plants damaged by 1.5 to 6 larvae/0.1 m^2 already were entering

the reproductive phase, and they did not respond to the moisture by producing additional growth. Plants damaged by 9 and 12 larvae/0.1 m^2, however, were less mature, and responded to the rain with a flush of growth. This extra growth ameliorated the initial loss in DM production.

Larval damage produced significant reductions in DM and nutrient yields at first bloom in 1982 and 1983. The declines were more severe in 1983 than 1982. Nine larvae/0.1 m^2 reduced DM, DDM, and CP yields at first bloom by 14.4, 14.9, and 14.3% in 1982 and by 36.8, 36.8, and 31.6% in 1983, respectively. Furthermore, DM and nutrient yield reductions within a year were proportional, suggesting that most of the reduction in nutrient yields was attributable to the decline in DM production.

Economic analysis

Trends in nutrient yields were reflected in the estimation of mean dollar values for both harvest systems (Table 19). There were no consistent trends at first bloom in dollar values in 1981. Values based on calendar dates, however, did decline proportionally with larval density. Values estimates in 1982 and 1983 also declined in direct proportion with larval density for both harvest systems.

Value estimates from 1982 and 1983 were used to calculate economic injury levels for VCW. Data from 1981 were not included because of the droughty conditions during this trial. Dollar losses were regressed against larval density using data from both years and forcing equations through the origin. The predicted loss per larva per 0.1 m^2 at first bloom for hay prices at \$61 and \$77/MT was \$4.67 and \$5.96/ha, respectively. Dollar losses per larva per 0.1 m^2 for a calendar-date harvest

Table 19. Effect of stubble injury by various densities on the dollar value returns of alfalfa hay where harvest is based on first bloom and calendar date

Year	Larvae per 0.1 m^2	First bloom		Calendar date	
		$61/MT	$77/MT	$61/MT	$77/MT
1981	0	146.58ab	186.57ab	137.86a	175.43a
	3	146.29ab	186.16ab	129.44ab	164.72ab
	6	125.15b	159.25b	105.05abc	133.68abc
	9	154.60a	196.73a	90.00c	114.52c
	12	147.61ab	187.22ab	94.57bc	120.34bc
1982	0	237.16a	301.78a	261.63a	322.92a
	1.5	215.70ab	274.48ab	212.36abc	270.22abc
	3	215.23ab	273.87ab	230.93ab	293.86ab
	6	223.64ab	284.58ab	177.55bcd	225.93bcd
	9	202.62ab	257.83ab	158.43cd	201.61cd
	12	185.33b	235.83b	126.55d	161.03d
1983	0	149.03a	189.64a	208.97a	265.91a
	1.5	139.70ab	177.77ab	186.34ab	237.12ab
	3	123.86abc	157.61abc	202.75a	258.00a
	6	113.91bc	144.86bc	168.13b	213.95b
	9	97.95c	124.64c	142.14c	180.87c

[a]Means followed by the same letter are not significantly (P = .05) different; Duncan's Multiple Range Test.

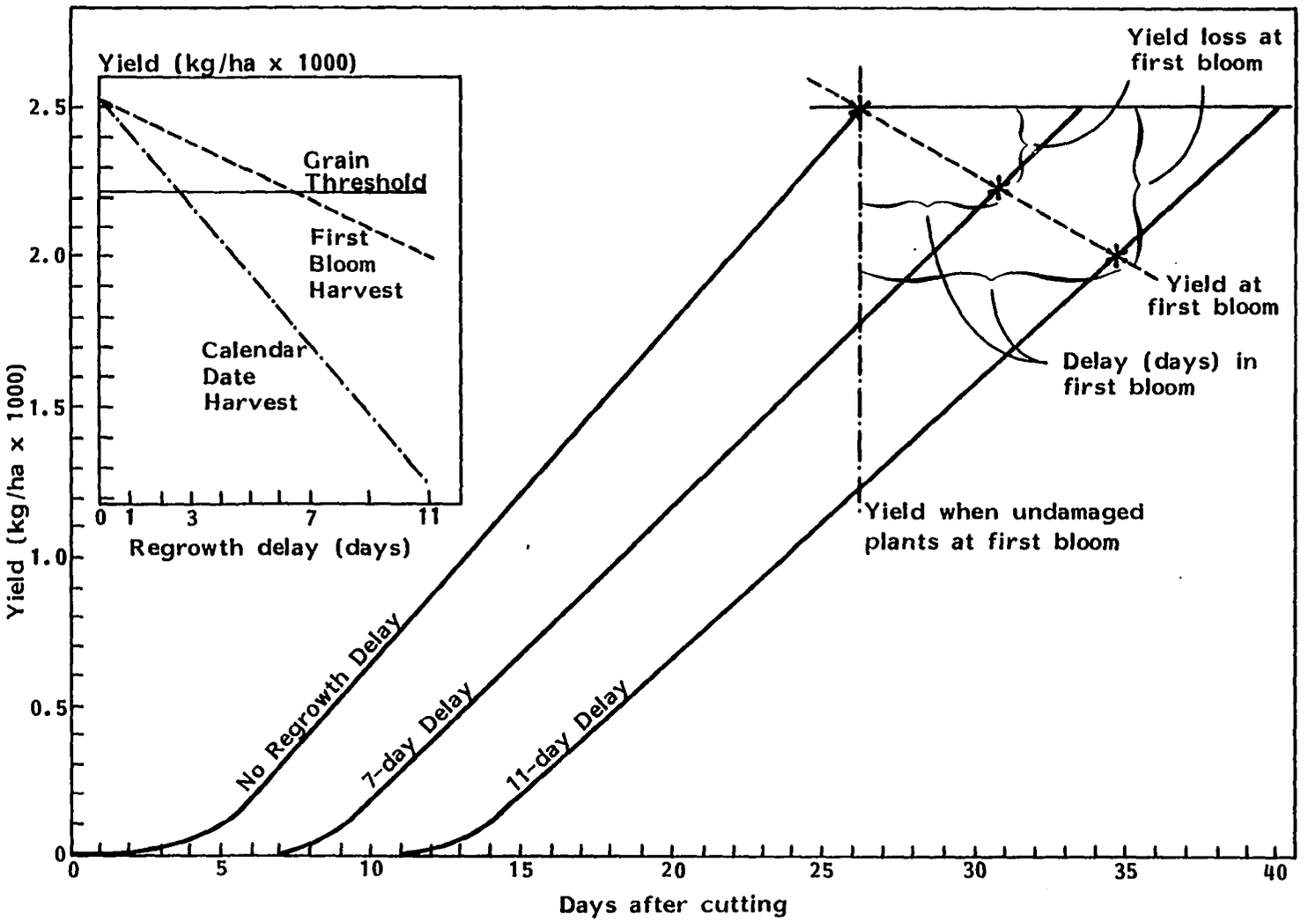
schedule were $7.90 and $10.04/ha, respectively. Economic injury levels (EIL) were calculated by dividing the cost of control by the estimated loss per larva. EILs for a harvest system based on first bloom ranged from 2.8 to 4.8 larvae/0.1 m^2 (Table 17). These levels are almost twice the EILs of 1.7 to 2.8 larvae/0.1 m^2 calculated for a calendar-date harvest system.

DISCUSSION

The results of this research demonstrate that 6 or greater larvae/ 0.1 m^2 are required to completely suppress alfalfa regrowth. Stubble injury had a more adverse effect on dry matter production than on plant development. Consequently, actual and simulated stubble injury produced two primary effects on regrowth: (1) a delay in plant development with a concomitant loss in DM, and (2) an additional loss in DM associated with a reduction in the subsequent rate of growth. These relationships are illustrated in Figure 11 for complete delays of regrowth, but the same relationships apply to injury caused by larvae (e.g., substitute larval density for length of regrowth delay). Regrowth quality was affected primarily by the relative delay in herbage chronology. No strong additional effect on herbage quality, other than the effect on herbage age, was evident. The delay in plant development and reduction in growth rates, however, were significant only when regrowth was completely delayed for more than 3 days. Likewise, these effects were significant only when larval densities were large enough to suppress regrowth almost completely (i.e., 6 or greater larvae/0.1 m^2).

The response of alfalfa regrowth to stubble injury was remarkably similar in both studies. This indicates that the damage simulation technique satisfactorily mimicked a complete suppression of regrowth caused by insect injury. Furthermore, these results suggest the primary effect of stubble injury was the removal of regrowth biomass with minimal adverse effects as a result of feeding toxicants or other larval activities.

Figure 11. Stylized response of alfalfa yield to complete regrowth delays of 7 and 11 days showing the developmental delay and yield loss at first bloom, and the yield loss for a calendar-date harvest system when undamaged plants are at first bloom


Yield (kg/ha x 1000)
Grain Threshold
First Bloom Harvest
Calendar Date Harvest
0 1 3 7 11
Regrowth delay (days)
Yield loss at first bloom
Yield at first bloom
Delay (days) in first bloom
Yield when undamaged plants at first bloom
No Regrowth Delay
7-day Delay
11-day Delay
Yield (kg/ha x 1000)
2.5
2.0
1.5
1.0
0.5
0
0 5 10 15 20 25 30 35 40
Days after cutting

The economic analysis of stubble injury would be simplified were it not for the fact that most alfalfa grown for consumption by livestock is harvested based on stage of plant development rather than calendar date (Smith 1975). Alfalfa may be harvested by calendar date for a number of reasons including the production of dehydrated pellets. Therefore, should yield-loss equations be based on yield differences for a particular sample date, such as day 35 in all years, or should loss equations be based on yield differences for the same stage of plant physiological development? In instances where alfalfa is harvested based on stage of development, such as first or 1/10 bloom, threshold calculations probably should be based on the yield loss relationship for the same stage of development (Fig. 11). The associated developmental delay can be ignored unless: (1) the delay caused the loss of an entire subsequent cutting (such as the last cutting of the year), or (2) delay in the last cutting did not allow enough time to replenish root reserves before the winter. Probably a delay in plant development of greater than 1 week would be needed before subsequent harvest schedules would be adversely affected. Otherwise, the grower still would realize the same number of cuttings, and assuming no significant carryover effects on dry matter production, yield loss will occur only during the cutting in which stubble feeding occurs. Stubble injury by AW during the second growth cycle has been found not to cause significant carryover effects on yield (Liu and Fick 1975).

In the present study, delay thresholds based on first bloom ranged from 4.4 to 7.5 days. First bloom was retarded by 1.2 and 3.4 days when regrowth was completely suppressed for 3 and 7 days, respectively. Con-

sequently, delays in first bloom associated with the calculated delay-loss thresholds probably would be within the range of 1 to 3.5 days. Therefore, the delay-loss thresholds calculated for a harvest system based on cutting at first bloom are valid, and damage for these durations probably would not adversely affect subsequent harvest schedules.

Likewise, economic injury levels calculated based on losses at first bloom indicated that control measures would be justified for 2.8 to 4.8 newly-molted, last-stage larvae/0.1 m^2. Stubble feeding by this range of larval densities would result in less than a complete delay of regrowth. Delays in plant development for infestations of 3 and 6 larvae/ 0.1 m^2 were 2.2 and 4.7 days, respectively. Thus, developmental delays caused by densities at the EIL most likely would fall within the range of 2 to 4 days. Again, this developmental delay is not excessive and probably would not appreciably alter subsequent harvest schedules.

A management program for VCW in alfalfa stubble can be developed from these results for a harvest system based on cutting at or near first bloom. If VCW larvae were present at economic levels, but most larvae were full grown and within several days of pupation, curative measures probably would not be needed. This is because most larvae probably would finish feeding and pupate before the delay-loss threshold of 4.5 to 7.5 days was exceeded. If, however, most larvae were at or near the beginning of the last larval stage, thus having ca. 75% of their total potential consumption remaining (Part I of this dissertation), the calculated EILs should be used (Table 17). In this instance, the economic threshold is set equal to the EIL, because the population is being

evaluated while maximal damage is occurring and when little or no further increase in the population would be expected.

If, however, alfalfa is harvested based on calendar date, the associated developmental delay at first bloom could be important because a delay may require the alteration of subsequent harvest schedules. In this instance, damage thresholds should be based on the yield-loss relationship for a sample date when the undamaged plants are at or near a desired stage of development. Delay loss thresholds for cutting by calendar date ranged from 2.6 to 4.3 days. Because hay for pelleting is green-chopped and removed in one operation, fields could be scouted for stubble injury one to two days after cutting. Curative measures would be justified if damage is expected to exceed the delay loss threshold, or if VCW populations exceed the calculated EILs (Table 17). EILs should be applied even if larvae are near pupation, because damage most likely would continue past the delay-loss threshold.

The results of the regrowth delay study also have implications for the management of stubble feeding by other defoliators, particularly the AW. Regrowth can be completely suppressed by defoliators during the three to four days while hay is being processed, without the crop suffering substantial economic losses. This is especially true in less intensively managed alfalfa. Consequently, fields can be scouted for stubble defoliators, including VCW, during this time and a decision made concerning curative measures once the hay is removed, without adversely affecting productivity.

Management of the AW usually involves early first cutting followed by the treatment of the stubble with insecticide if needed (DeWitt and

Stockdale 1976, Onstad and Shoemaker 1984). Recent research in Kentucky (Brown, unpublished data) has demonstrated that AW populations also can be suppressed by inducing natural epizootics of the entomopathogen Erynia sp. Epizootics are induced by cutting and windrowing the alfalfa hay, which creates a favorable microenvironment for fungal development. The incubation period of the fungus is five to six days, consequently stubble injury during this time must be tolerated. Delay-loss thresholds were within this range for on-farm hay ($61/MT) that is harvested based on stage of plant development. Therefore, the inducement of fungal epizootics by harvest procedures is a viable alternative to stubble sprays for less intensely managed alfalfa, if the grower is willing to accept the risk of little control should the fungal epizootic fail to develop.

SUMMARY AND CONCLUSIONS

The response of alfalfa to actual and simulated stubble injury by the variegated cutworm (VCW) was investigated in a laboratory and two field studies. The objectives of this research were to: (1) characterize the damage-response syndrome of alfalfa to stubble injury in terms of growth, development, and partitioning, (2) assess the effects of complete regrowth delays for varying periods on subsequent growth and yield, (3) elucidate the relationships between larval density and alfalfa growth and yield, and (4) quantify VCW larval development and foliage consumption on alfalfa. With these data, a final overall objective was (5) to develop economic injury levels and management practices for VCW in alfalfa, and make progress towards the development of a more comprehensive management program for stubble-feeding insects in alfalfa.

Larvae exhibited 6 or 7 larval stages in the laboratory, with most larvae (61.3%) undergoing 7 molts. Larvae with 6 and 7 molts required 35.6 and 32.8 days for development at 24°C, and consumed 352.6 and 442.4 mg of foliage, respectively. Mode-7 larvae consumed 75% of their total consumption during the last stage, and both modes consumed about 95% of total consumption from stage 5 to pupation. Larval and adult dry weights indicated that larvae with 7 molts probably were representative of feral individuals. Consequently, an alfalfa-consumption model was developed using data for mode-7 larvae. Based on these results, the damage potential of VCW during the first cutting probably will not be large, if cutting occurs before most larvae have entered the last stage. Because of the high rate of consumption by last-stage larvae, however,

a small number of these larvae present after cutting may cause considerable damage to alfalfa stubble.

The response of alfalfa regrowth to the duration and intensity of stubble injury by VCW was investigated in several field studies. The duration component of stubble damage was examined in a study of the effects of a complete regrowth suppression for varying times on alfalfa productivity. Complete regrowth suppression was simulated by hand-picking foliage for 1, 3, 7, and 11 days. The effect of damage intensity was investigated in a separate field study of the response of alfalfa to stubble feeding by various densities of VCW larvae. This study demonstrated that newly-molted, last-stage larvae injured regrowth for 10 to 15 days. This time range is similar to the stadia observed in the laboratory for last-stage larvae. Densities of 6 and greater larvae/ 0.1 m^2 were needed to completely suppress alfalfa regrowth. Lower densities suppressed regrowth only partly by reducing the rate of shoot initiation and damaging shoots that did grow.

Complete regrowth suppression for 1 and 3 days did not significantly retard plant development or alter rates of growth and partitioning. The lack of effect of these delays probably was a consequence of the greatly reduced growth rate during the first 3 days of regrowth. Growth rates increased substantially after the third day. Plants with regrowth delayed for more than 3 days seemed to produce herbage at the greater rate immediately, thus avoiding most of the initial 3 days of reduced growth.

Analysis of growth and partitioning rates generally showed similar effects on regrowth for both actual and simulated stubble injury. This

suggests that the simulation technique satisfactorily mimicked actual defoliation where regrowth is suppressed completely. Stubble injury caused delays in plant development and reduced subsequent crop growth rates (CGR). Most of the reduction in CGR was caused by a decline in the growth rate of support structures. Leaf and leaf area growth rates generally were not significantly reduced by stubble damage. The suppression in support growth relative to leaf and leaf area growth rates resulted in an increased leaf area ratio. Leaf area ratio was enhanced by a combined increase in the leaf weight ratio and specific leaf area. The increase in leaf weight ratio was attributed to the production of heavier leaves rather than the production of more leaves per unit of total dry weight. The main difference in plant response in both studies was that actual larval damage increased the production rate of stem height, whereas, stem-height production was not significantly increased by simulated stubble defoliation. The cause of this discrepancy was not determined. The changes in plant growth and partitioning however, were significant only when regrowth was completely suppressed for 7 or more days. Likewise, growth and partitioning were affected significantly in all years only when larval damage was severe enough to suppress regrowth almost completely (e.g., densities of 6 or greater larvae/0.1 m^2). Although lesser densities significantly affected regrowth in some years, these densities did not consistently affect regrowth in all years.

The combined results of both studies indicated that a complete suppression of regrowth for 7 or more days caused: (1) an initial delay in plant growth and development with a concomitant loss in dry matter, and (2) an additional dry matter loss caused by the reduction in sub-

sequent growth rates. Damaged plants partitioned more leaf area per unit of dry weight through relative increases in both leaf weight per unit of total dry weight and leaf area per unit of leaf weight. The latter trend resulted in a reduction in leaf density, which has the effect of increasing leaf area available for light interception without a concomitant increase in leaf biomass. The overall effect of the changes in plant partitioning was to minimize the adverse effects of insect-induced stubble injury by maintaining growth rates of leaf weight and area at the expense of support structure growth.

A hypothesis was postulated to explain the changes in partitioning by damaged plants. The hypothesis is based on the depletion of stored carbohydrate reserves, while regrowth is being suppressed. Once defoliation ceases, regrowth presumably would proceed without the benefit of large reserves of stored carbohydrates. New shoots, therefore, would be more dependent on currently produced photosynthates for growth. Because assimilate sources (i.e., leaves) tend to satisfy their own needs before exporting assimilates (Cook and Evans 1978), leaf growth probably would not be suppressed greatly. Growth rates of support structures (i.e., assimilate sinks), however, most likely would be suppressed more severely, because of the loss of stored carbohydrates to maintain growth and the inability of current photosynthesis to make up the difference. Although this simple hypothesis may explain the observed changes in plant partitioning, it is possible that other factors, such as hormone levels in damaged plants, may be partly responsible for the altered rates of growth and partitioning.

A replacement feed-cost analysis was conducted for both studies, using commodity prices for on-farm and off-farm hay. Dollar-loss equations were generated for harvest systems where cutting is based on either plant stage, such as first bloom, or calendar date for a date when undamaged plants are near the desired stage for harvest. Depending on commodity price and control costs, delays of 4.4 to 7.5 days would justify the cost of artificial control for a system where cutting occurs at first bloom. These values drop to a range of 2.6 to 4.3 days for a calendar-date harvest system. Economic injury levels (EIL) also were calculated using data from the larval infestation study. EILs for a harvest system based on first bloom were 2.8 to 4.8 newly-molted, last-stage larvae/0.1 m^2, and EILs for a calendar-date system were 1.7 to 2.8 newly-molted, last-stage larvae/0.1 m^2. Therefore, inclusion of the delay in plant development as a loss criterion reduced action thresholds by about half.

Based on the results of these studies, a management program was developed for VCW in alfalfa. Guidelines also were proposed for the management of other stubble defoliators. The action thresholds and recommendations generated by this research will permit more effective management of VCW and other defoliators in alfalfa. Furthermore, the proposed program should minimize economic losses caused by VCW in alfalfa and reduce unnecessary applications of insecticides during future outbreaks.

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APPENDIX A. MEANS AND ANALYSIS OF DATA FOR THE DELAY OF REGROWTH STUDY

Table 19. Effect of complete regrowth suppression for various periods (days) on mean developmental stage of alfalfa (1 = vegetative, 2 = bud, and 3 = flower)

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	1.00a	1.08a	1.32a	2.00a	--	--
1	1.00a	1.00b	1.16b	1.95a	--	--
3	1.00a	1.00b	1.22b	1.83a	--	--
7	--	1.00b	1.06c	1.57b	--	--
11	--	1.00b	1.00c	1.23c	--	--
Trial 2 - 1981						
0	1.00a	1.06a	1.30a	1.50a	1.98a	2.22a
1	1.00a	1.03ab	1.24a	1.50a	1.93a	2.14a
3	1.00a	1.06a	1.14b	1.41a	1.90a	2.16a
7	--	1.00b	1.12b	1.35ab	1.65b	2.02a
11	--	1.00b	1.00c	1.16b	1.39c	1.62b
Trial 1 - 1982						
0	1.00a	1.00a	1.02a	1.12a	1.70a	2.32a
1	1.00a	1.00a	1.01a	1.10a	1.62ab	2.33a
3	1.00a	1.00a	1.00a	1.06ab	1.66ab	2.24a
7	1.00a	1.00a	1.00a	1.02b	1.54b	2.12a
11	1.00a	1.00a	1.00a	1.01b	1.39c	1.77b
Trial 2 - 1982						
0	1.00a	1.00a	1.17a	1.66a	1.90a	1.98a
1	1.00a	1.00a	1.11ab	1.42ab	1.84ab	1.84ab
3	1.00a	1.00a	1.08bc	1.50b	1.69b	1.88ab
5	1.00a	1.00a	1.03cd	1.19c	1.69b	1.74abc
7	1.00a	1.00a	1.00d	1.20c	1.43c	1.49cd
11	1.00a	1.00a	1.00d	1.01d	1.16d	1.29d

[a]Means followed by the same letter are not significantly (P = .05); Duncan's Multiple Range Test.

Table 20. Effect of complete regrowth suppression for various periods (days) on percentage alfalfa stems in bud stage

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	0	9.0a	30.0a	64.0a	--	--
1	0	0b	16.0b	57.0a	--	--
3	0	0b	22.0b	64.0a	--	--
7	0	0b	6.0c	57.0a	--	--
11	0	0b	0c	23.0b	--	--
Trial 2 - 1981						
0	0	5.6a	30.4a	46.4a	26.4b	5.6a
1	0	3.2ab	20.8b	45.6a	44.8a	8.8b
3	0	6.4a	10.4c	37.6ab	36.8ab	6.4a
7	0	0b	15.2bc	32.0ab	33.6ab	8.8a
11	0	0b	0d	16.0b	24.0b	16.8a
Trial 1 - 1982						
0	0	0	1.6a	12.0a	69.6a	44.0a
1	0	0	0.8a	10.4a	63.2ab	46.4a
3	0	0	0a	5.6ab	65.6ab	50.4a
7	0	0	0a	1.6b	54.4b	65.6ab
11	0	0	0a	0.8b	39.2c	74.4b
Trial 2 - 1982						
0	0	0	15.2a	60.8a	72.8a	44.8a
1	0	0	11.2s	40.8ab	68.8a	33.6ab
3	0	0	8.0ab	49.6b	59.2ab	32.0ab
5	0	0	3.2bc	20.0c	54.4b	35.2ab
7	0	0	0c	20.0c	40.0c	32.8ab
11	0	0	0c	0.8d	16.0d	25.6b

[a]See footnote, Table 19.

Table 21. Effect of complete regrowth suppression for various periods (days) on the percentage of flowering alfalfa stems

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	0	0	1.0	18.0a	--	--
1	0	0	0	19.0a	--	--
3	0	0	0	9.0ab	--	--
7	0	0	0	1.0b	--	--
11	0	0	0	0b	--	--
Trial 2 - 1981						
0	0	0	0	1.6a	36.0a	57.6a
1	0	0	1.6	2.4a	24.0bc	52.0a
3	0	0	0	1.6a	26.4b	53.6a
7	0	0	0	1.6a	16.0c	45.6a
11	0	0	0	0a	2.5d	22.4b
Trial 1 - 1982						
0	0	0	0	0	0	45.6a
1	0	0	0	0	0	43.2a
3	0	0	0	0	0	36.8a
7	0	0	0	0	0	23.2b
11	0	0	0	0	0	1.6c
Trial 2 - 1982						
0	0	0	0	0	5.6a	26.4ab
1	0	0	0	0	8.0a	16.0bc
3	0	0	0	0	4.8a	28.0a
5	0	0	0	0	7.2a	19.2b
7	0	0	0	0	1.6b	8.0c
11	0	0	0	0	0b	1.6d

[a]See footnote, Table 19.

Table 22. Effect of complete regrowth suppression for various periods (days) on mean stem height (cm) of alfalfa

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	7.20a	18.29a	24.87a	40.59a	--	--
1	6.25a	16.47a	24.14a	36.00a	--	--
3	3.39b	14.02b	23.78a	34.60a	--	--
7	--	10.03c	19.32b	34.13a	--	--
11	--	2.93d	13.22c	27.97b	--	--
Trial 2 - 1981						
0	6.49a	16.39a	19.38a	21.78ab	25.82a	37.52a
1	6.01a	15.12a	20.34a	24.70a	26.85a	36.42a
3	4.18b	12.77b	17.17ab	18.43bc	24.75ab	36.18a
7	--	9.63c	14.72b	17.58bc	21.32bc	35.20a
11	--	1.75d	8.99c	14.70c	20.73c	31.30b
Trial 1 - 1982						
0	3.18a	11.32a	23.83a	38.09a	44.29a	48.31b
1	2.40b	10.28a	24.33a	39.88a	45.98a	52.41a
3	2.29b	9.86a	23.68a	38.54a	47.48a	55.06a
7	--	5.69b	17.47b	33.32b	41.67ab	49.74ab
11	--	1.69c	10.83c	26.87c	36.59b	41.56c
Trial 2 - 1982						
0	3.18a	17.97a	37.42a	47.09a	60.94a	59.88a
1	2.81a	18.57a	35.26a	45.02a	55.74ab	52.83ab
3	2.47ab	16.88a	32.00ab	46.02a	59.42ab	54.76ab
5	1.82b	13.91b	31.66ab	42.76a	55.25ab	53.92ab
7	--	7.14c	27.62b	39.49a	50.50b	51.86ab
11	--	1.50d	14.86c	27.76b	38.90c	45.40b

[a]See footnote, Table 19.

Table 23. Effect of complete regrowth suppression for various periods (days) on number of leaves per stem of alfalfa

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	6.18a	12.48a	21.63a	36.85a	--	--
1	5.12ab	10.66a	18.73a	33.13ab	--	--
3	4.23b	10.47a	19.27a	31.29ab	--	--
7	--	7.24b	14.56b	26.93b	--	--
11	--	2.82c	8.88c	17.63c	--	--
Trial 2 - 1981						
0	5.11a	9.82a	14.66a	21.93ab	34.02a	46.48a
1	4.75a	9.06a	14.37a	23.24a	35.03a	39.66a
3	4.01b	8.41a	12.82ab	16.88c	31.06a	38.34a
7	--	6.62b	11.38b	17.52bc	27.73b	38.02a
11	--	2.56c	6.48c	12.26d	18.37c	26.32b
Trial 1 - 1982						
0	2.86a	7.58a	11.78a	24.23a	38.46a	65.68a
1	2.30b	7.18a	11.74a	23.11a	33.83ab	63.82a
3	2.22b	6.74a	10.97a	22.45a	37.79a	59.42a
7		4.93b	9.07b	18.57b	32.10b	60.85a
11		2.54c	6.74c	13.94c	25.75c	43.54b
Trial 2 - 1982						
0	2.98a	8.50ab	19.74a	32.03a	43.48a	41.64ab
1	3.02a	8.82a	17.82ab	28.24a	38.60ab	35.45bc
3	2.78a	7.73bc	15.75bc	29.82a	37.86ab	44.46a
5	2.16b	6.80c	13.82c	23.88b	38.34ab	39.78abc
7	--	4.52d	10.39d	19.78b	30.84b	34.22c
11	--	2.38e	6.54e	11.85c	21.77c	27.66d

[a]See footnote, Table 19.

Table 24. Effect of complete regrowth suppression for various periods (days) on mean number of main-stem nodes and stem density (no./m^2) of alfalfa in 1982

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Nodes/stem - Trial 1						
0	--	6.08a	8.12a	10.76a	13.26a	14.12a
1	--	5.48a	8.00a	11.44a	12.88a	13.88a
3	--	5.54a	7.90a	10.62a	13.20a	14.00a
7	--	4.24b	6.82b	9.36b	12.18b	13.34b
11	--	2.81c	5.40c	7.63c	10.80c	11.78c
Trial 2						
0	3.62a	6.94a	9.73a	11.32a	13.69a	13.65a
1	3.51a	6.84a	9.16a	10.98a	12.89b	12.87b
3	3.22ab	6.70a	8.49b	11.04a	12.70b	13.34ab
5	2.78b	5.82b	7.98b	9.58b	12.18b	12.72b
7	--	4.65c	6.93c	9.23b	10.58c	11.44c
11	--	2.58d	5.12d	7.08c	9.03d	10.44d
Stem density - Trial 1						
0	660a	1178a	1140a	791a	751ab	737a
1	572a	995b	838b	852a	786a	751a
3	591a	936bc	865b	804a	758ab	746a
7	0b	848c	727b	738a	648ab	653a
11	0b	475d	746b	721a	633b	650a
Trial 2						
0	1160a	1176a	975a	732a	778a	640a
1	1080a	1027a	884a	747a	672a	588a
3	1093a	1091a	943a	656a	737a	628a
5	874a	939a	929a	778a	634a	603a
7	0b	965a	858a	771a	738a	575a
11	0b	646b	860a	705a	668a	602a

[a]See footnote, Table 19.

Table 25. Effect of complete regrowth suppression for various periods (days) on leaf weight ratio (gm/gm) on alfalfa regrowth

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	.518a	.527a	.490a	.436a	--	--
1	.512a	.520a	.501ab	.455ab	--	--
3	.553a	.564a	.496a	.464ab	--	--
7	--	.584a	.532bc	.475bc	--	--
11	--	.581a	.551c	.501c	--	--
Trial 2 - 1981						
0	.622a	.537a	.512a	.516ab	.487a	.380a
1	.620a	.535a	.518a	.496a	.487a	.367a
3	.601a	.553ab	.545a	.550bc	.506ab	.371a
7	--	.596b	.536a	.561bc	.538bc	.421b
11	--	.582ab	.624b	.571c	.580c	.465c
Trial 1 - 1982						
0	.514a	.607a	.549a	.487ab	.441ab	.388a
1	.453b	.603a	.549a	.469a	.410c	.371a
3	.471b	.619a	.554a	.475a	.404c	.364a
7	--	.554a	.594b	.514b	.437b	.390a
11	--	.543a	.652c	.555c	.465a	.430b
Trial 2 - 1982						
0	.559a	.525a	.467a	.445a	.394a	.342a
1	.530a	.510a	.481a	.455a	.414a	.356ab
3	.538a	.532a	.485a	.438a	.408a	.373abc
5	.484b	.548a	.500a	.463a	.407a	.383bcd
7		.631b	.537b	.472ab	.424a	.398cd
11		.683c	.591c	.508b	.482b	.415d

[a]See footnote, Table 19.

Table 26. Effect of complete regrowth suppression for various periods (days) on leaf area ratio (cm^2/gm) on alfalfa

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	82.2a	110.6a	83.8a	106.6a	--	--
1	77.4a	111.2a	93.8b	107.8a	--	--
3	73.1a	110.1a	84.0a	107.2a	--	--
7	--	108.6a	90.0ab	116.8ab	--	--
11	--	86.3b	86.2ab	131.0b	--	--
Trial 2 - 1981						
0	121.5a	93.2a	84.2a	94.2a	101.2a	89.5a
1	109.0a	93.8a	88.1a	103.8ab	111.9ab	81.2a
3	105.6a	80.6a	85.0a	103.7ab	118.9ab	85.4a
7		93.1a	78.7a	113.9bc	121.2b	101.9b
11		66.5a	88.4a	122.8c	151.2c	112.5c
Trial 1 - 1982						
.0	80.38a	134.2a	97.4a	98.0a	86.2a	79.2a
1	67.72ab	131.3a	101.0a	102.9a	90.6ab	79.9a
3	63.58b	137.1a	96.9a	103.0a	91.1ab	79.0a
7	--	135.6a	112.3b	105.5ab	92.7ab	81.2a
11	--	96.4b	117.5b	113.3b	98.3b	94.3b
Trial 2 - 1982						
0	87.6a	100.4a	123.0a	97.8a	96.9a	88.0a
1	78.2ab	98.6a	127.6ab	102.9ab	100.6a	93.4a
3	80.8a	99.6a	124.0ab	98.9a	100.5a	89.3a
5	64.3b	101.0a	139.6abc	113.6b	105.0ab	102.1ab
7		111.8a	146.9bc	113.6b	116.4bc	112.2bc
11		112.4a	156.0c	112.5b	126.3c	122.9c

[a]See footnote, Table 19.

Table 27. Effect of complete regrowth suppression for various periods (days) on weight (mg) per leaf of alfalfa

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	4.47a	7.35a	6.42a	6.59a	--	--
1	4.36a	6.28ab	7.52a	6.53a	--	--
3	4.22a	6.75a	6.67a	6.42a	--	--
7	--	7.24a	7.18a	7.11ab	--	--
11	--	4.90b	6.97a	7.54b	--	--
Trial 2 - 1981						
0	6.80a	8.63a	7.57a	6.25ab	4.68a	4.75a
1	7.08a	7.29ab	8.11a	5.99ab	4.42a	5.10ab
3	5.39b	9.99a	8.10a	6.56a	4.53a	5.31ab
7	--	7.13ab	7.22a	5.72b	4.79a	5.82bc
11	--	5.89b	7.06a	6.24ab	5.78b	6.42c
Trial 1 - 1982						
0	3.57a	7.99ab	12.27a	11.75a	9.66a	6.71a
1	2.79b	7.67ab	12.14a	11.68a	9.63a	7.41ab
3	3.26ab	8.43a	12.85a	11.29a	9.45a	7.36ab
7	0	5.73b	11.55ab	12.41ab	10.41ab	7.97b
11	0	2.68b	10.48b	13.63b	11.92b	8.34b
Trial 2 - 1982						
0	3.51a	8.62a	9.36a	9.50a	8.49a	6.52ab
1	2.68b	8.50a	10.01a	9.86a	8.83a	6.23a
3	2.53bc	9.10a	9.88a	9.63a	8.00a	6.59ab
5	2.06c	8.20ab	11.23a	10.82ab	8.72a	7.43ab
7	--	7.22b	10.96a	11.62b	9.08a	7.72b
11	--	3.15c	9.46a	10.89ab	9.15a	7.06ab

[a]See footnote, Table 19.

Table 28. Effect of complete regrowth suppression for various periods (days) on area (cm^2) per leaf of alfalfa

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	0.71a	1.52a	1.10a	1.64a	--	--
1	0.66a	1.35a	1.39b	1.57a	--	--
3	0.56a	1.33a	1.13a	.151a	--	--
7	--	1.34a	1.23ab	1.77ab	--	--
11	--	0.71b	1.09a	2.03b	--	--
Trial 2 - 1981						
0	1.33a	1.50a	1.24ab	1.15a	0.98a	1.12a
1	1.25ab	1.27a	1.38a	1.26a	1.02a	1.11a
3	0.95b	1.39ab	1.26a	1.24ab	1.05a	1.22a
7	--	1.11ab	1.09bc	1.16a	1.08a	1.41b
11	--	0.49b	1.00c	1.33b	1.45b	1.55b
Trial 1 - 1982						
0	0.56a	1.75a	2.17ab	2.37a	1.97a	1.38a
1	0.41b	1.68a	2.24a	2.58a	2.12ab	1.60ab
3	0.43b	1.85a	2.25a	2.45a	2.13ab	1.60ab
7	0c	1.26b	2.18ab	2.54a	2.22ab	1.66ab
11	0c	0.47c	1.89b	2.80a	2.51b	1.84b
Trial 2 - 1982						
0	0.56a	1.64a	2.46a	2.06a	2.08a	1.68ab
1	0.40b	1.65a	2.68a	2.25ab	2.16a	1.66ab
3	0.39b	1.71a	2.51a	2.18ab	1.97a	1.58a
5	0.27c	1.51ab	3.19a	2.67bc	2.26a	2.02ab
7	--	1.29b	2.98a	2.79c	2.51a	2.18ab
11	--	0.52c	2.48a	2.42abc	2.39a	2.09b

[a]See footnote, Table 19.

Table 29. Effect of complete regrowth suppression for various periods (days) on specific leaf weight (mg/cm^2) of alfalfa

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	6.33a	4.79a	5.87a	4.10a	--	--
1	6.64ab	4.70a	5.40b	4.25a	--	--
3	7.58b	5.16a	5.93a	4.37a	--	--
7	--	5.44a	5.91a	4.09a	--	--
11	--	6.78b	6.41a	3.89a	--	--
Trial 2 - 1981						
0	5.16a	5.79a	6.13ab	5.48a	4.84a	4.29ab
1	5.71ab	5.74a	5.95a	4.80b	4.35b	4.65a
3	5.76b	7.33a	6.43abc	5.31ab	4.33b	4.34ab
7	--	6.44a	6.83bc	4.93ab	4.49ab	4.17b
11	--	8.02a	7.21c	4.77b	3.90c	4.18b
Trial 1 - 1982						
0	6.50a	4.55a	5.64a	5.00a	4.97a	4.94a
1	6.72a	4.62ab	5.46a	4.59a	4.55a	4.69a
3	7.49b	4.54a	5.73a	4.65a	4.46a	4.63a
7	--	4.37a	5.30a	4.90a	4.75a	4.83a
11	--	5.68b	5.58a	4.94a	4.77a	4.59a
Trial 2 - 1982						
0	6.49a	5.29a	3.81a	4.61a	4.07a	3.92ab
1	6.91ab	5.19a	3.78a	4.45a	4.21a	3.82ab
3	6.57a	5.37a	3.94a	4.46a	4.11a	4.27a
5	7.61b	5.47a	3.62a	4.11a	3.95a	3.77ab
7	--	5.69ab	3.69a	4.16a	3.68a	3.56b
11	--	6.27b	3.87a	4.53a	3.84a	3.40b

[a]See footnote, Table 19.

Table 30. Effect of complete regrowth suppression for various periods (days) on leaf area index (m^2/m^2 of ground) of alfalfa

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	0.32a	1.35a	1.75a	3.65a	--	--
1	0.26ab	1.31a	1.86a	3.32a	--	--
3	0.19b	1.09a	1.62a	3.08a	--	--
7	--	0.68b	1.24b	2.90a	--	--
11	--	0.20c	0.85c	2.68a	--	--
Trial 2 - 1981						
0	0.68a	1.24a	1.37a	1.74b	2.21ab	2.72a
1	0.49b	1.13a	1.61a	2.23a	2.59a	2.42a
3	0.39b	0.88b	1.25a	1.81ab	2.42a	2.47a
7	--	0.56c	0.70b	1.57b	1.88b	2.81a
11	--	0.07d	0.42c	0.99c	1.89b	2.58a
Trial 1 - 1982						
0	0.10a	0.90a	1.79a	2.49ab	3.05ab	3.59a
1	0.05b	0.70b	1.39b	2.80a	3.58a	3.64a
3	0.05b	0.65b	1.24b	2.57a	3.43a	3.46a
7	--	0.36c	0.97c	2.00bc	2.56bc	3.24ab
11	--	0.04d	0.51d	1.54c	2.11c	2.76b
Trial 2 - 1982						
0	0.16a	1.07a	2.44a	2.54ab	3.74a	3.54a
1	0.11ab	0.94ab	2.39a	2.91ab	3.39a	3.40a
3	0.11ab	0.92ab	2.18a	2.56ab	3.48a	3.52a
5	0.07b	0.69b	2.49a	3.23a	3.36a	4.02a
7		0.38c	1.78a	2.18bc	3.24ab	3.54a
11		0.09d	0.97b	1.44c	2.28b	3.34a

[a]See footnote, Table 19.

Table 31. Effect of complete regrowth suppression for various periods (days) on yield (kg/ha) of alfalfa regrowth

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	383a	1225a	2082a	3448a	--	--
1	330ab	1171a	1959a	3068ab	--	--
3	260b	979a	1922a	2852ab	--	--
7	--	628b	1380b	2455bc	--	--
11	--	238c	984c	2016c	--	--
Trial 2 - 1981						
0	566a	1328a	1640a	1867a	2164a	3113a
1	452b	1207ab	1798a	2157a	2331a	3151a
3	366b	1120b	1462a	1749ab	2078a	2982a
7	--	605c	889b	1386b	1531b	2808a
11	--	105d	469c	795c	1244b	2329b
Trial 1 - 1982						
0	131a	671a	1836a	2533a	3540a	4525a
1	74b	528b	1370b	2702a	3953a	4584a
3	72b	478b	1283b	2502a	3771a	4412a
7	--	272c	863c	1878b	2767b	3976a
11	--	43d	438d	1346c	2155c	2913b
Trial 2 - 1982						
0	178a	1058a	1981a	2628a	3885a	4110a
1	142ab	953a	1864a	2810a	3337ab	3676ab
3	138ab	923a	1748a	2602a	3479ab	3882ab
5	107b	693b	1752a	2820a	3140ab	3902ab
7	--	338c	1220b	1916b	2760b	3184ab
1	--	84d	620c	1275c	1787c	2715b

[a]See footnote, Table 19.

Table 32. Effect of complete regrowth suppression for various periods (days) on support component of alfalfa yield (kg/ha)

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	184a	582a	1063a	1982a	--	--
1	161ab	562a	985a	1692ab	--	--
3	116b	431b	977a	1556ab	--	--
7	--	265c	657b	1303bc	--	--
11	--	101d	446c	1019c	--	--
Trial 2 - 1981						
0	214a	616a	881a	942ab	1054a	1944a
1	172b	559ab	803ab	1047a	1126a	2034a
3	146b	503b	666b	947ab	1047a	1907ab
7	--	244c	412c	772b	824b	1639b
11	--	45d	179d	459c	717b	1260c
Trial 2 - 1982						
0	63a	265a	829a	1299a	1979a	2765a
1	41b	210b	621b	1437a	2335a	2880a
3	38b	182b	574b	1312a	2243a	2810a
7	--	119c	351c	913b	1526b	2429a
11	--	20d	152d	605c	1153c	1664b
Trial 2 - 1982						
0	78a	505a	1056a	1461a	2366a	2719a
1	67ab	469a	975a	1547a	1965ab	2391ab
3	65ab	434ab	897a	1460a	2060ab	2433ab
5	53b	318b	891a	1526a	1877ab	2432ab
7	--	125c	570b	1017b	1603b	1922ab
11	--	27c	254c	629b	932c	1596b

[a]See footnote, Table 19.

Table 33. Effect of complete regrowth suppression for various periods (days) on leaf component of alfalfa yield (kg/ha)

Regrowth delay (days)	Days after cutting[a]					
	7	14	21	28	35	42
Trial 1 - 1981						
0	200a	643a	1020a	1465a	--	--
1	168ab	609a	974a	1371a	--	--
3	144b	548b	944a	1294ab	--	--
7	--	362b	723b	1153ab	--	--
11	--	138c	538c	997b	--	--
Trial 2 - 1981						
0	352a	712a	837a	925ab	1110a	1169a
1	280b	648ab	916a	1110a	1206a	1127a
3	220b	617b	797a	801bc	1031a	1075a
7	--	360a	478b	615c	711b	1169a
11	--	60d	290c	336d	527b	1069a
Trial 1 - 1982						
0	68a	407a	1007a	1235a	1561a	1760a
1	34b	318b	749b	1265a	1618a	1704a
3	34b	296b	709b	1190a	1528a	1602a
7	--	153c	511c	965b	1205b	1547a
11	--	23d	286d	742c	1002b	1249b
Trial 2 - 1982						
0	99a	553a	925a	1167a	1519a	1391a
1	75ab	484a	889a	1263a	1372ab	1285a
3	73ab	489a	851ab	1143ab	1419ab	1449a
5	55b	375b	861ab	1295a	1264ab	1470a
7	--	212c	650b	899b	1157bc	1263a
11	--	57d	366c	646c	855c	1120a

[a]See footnote, Table 19.

Table 34. Effect of complete regrowth suppression for various periods (days) on *in vitro* digestible dry matter (%) of alfalfa

Regrowth delay (days)	Days after cutting[a]			
	21	28	35	42
Trial 1 - 1981				
0	70.07a	69.99a	--	--
1	70.12a	70.92ab	--	--
3	74.25b	70.79ab	--	--
7	76.50b	72.40ab	--	--
11	78.02b	73.67b	--	--
Trial 2 - 1981				
0	74.17ab	66.70a	66.49a	64.31a
1	73.30a	66.83a	66.48a	63.84a
3	75.62ab	65.11a	66.91ab	64.78a
7	76.43b	66.72a	69.37bc	65.18ab
11	79.68c	69.38b	70.91c	67.09b
Trial 1 - 1982				
0	75.73a	69.08a	68.32ab	60.33a
1	79.51a	69.86ab	69.00ab	61.20a
3	81.51a	68.32a	67.68a	61.02a
7	79.07a	72.00b	69.58b	61.56a
11	83.97a	74.92c	71.54c	64.11b
Trial 2 - 1982				
0	66.26a	62.41a	62.34a	60.73a
1	67.95ab	63.35ab	62.95ab	61.73a
3	67.78ab	62.54a	63.07ab	60.96a
5	69.31b	63.64ab	64.83ab	62.34a
7	71.46c	65.53b	62.30b	62.71ab
11	75.24d	69.94c	67.60c	64.79b

[a]See footnote, Table 19.

Table 35. Effect of complete regrowth suppression for various periods (days) on crude protein content (%) of alfalfa

Regrowth delay (days)	Days after cutting[a]			
	21	28	35	42
Trial 1 - 1981				
0	27.97a	24.41a	--	--
1	27.47a	24.72ab	--	--
3	27.91a	25.10ab	--	--
7	31.59b	26.02b	--	--
11	35.84c	29.32c	--	--
Trial 2 - 1981				
0	24.20a	22.52a	24.21a	24.50a
1	24.39a	23.47ab	25.09a	24.56a
3	25.05a	23.38ab	26.39b	25.33ab
7	27.35b	24.68b	28.48c	26.60bc
11	32.44c	26.55c	30.07d	27.41c
Trial 1 - 1982				
0	26.30a	21.90ab	18.68ab	17.71ab
1	26.26a	20.93a	17.79a	17.31a
3	27.42a	21.66ab	18.44ab	17.73ab
7	30.84b	23.14bc	19.52bc	18.68ab
11	36.68c	24.26c	20.43c	19.13b
Trial 2 - 1982				
0	24.91a	21.23a	19.27a	18.86a
1	25.20a	20.66a	19.22a	19.45ab
3	24.96a	21.12a	20.42ab	19.97abc
7	27.86b	23.40b	21.22b	21.83c
11	32.20c	25.77c	23.85c	21.27bc

[a]See footnote, Table 19.

APPENDIX B. MEANS AND ANALYSIS OF DATA FOR THE VARIEGATED CUTWORM LARVAL INFESTATION STUDY

Table 36. Response of alfalfa regrowth to stubble injury by various densities of newly-molted, last-stage variegated cutworms in 1981

Larvae per 0.1 m^2	Days after cutting[a]				
	7	14	21	28	35
Height (cm)					
0	7.66a	19.90a	25.45a	25.87a	35.16a
3	4.13b	15.49a	23.32a	24.70ab	30.03ab
6	2.02c	9.30b	14.23b	19.30bc	27.98b
9	0.36d	3.46c	12.11b	18.25c	28.78ab
12	0.38d	4.09c	12.38b	21.58abc	31.31ab
Stem density (no./m^2)					
0	666a	1536a	1452a	1236ab	1204a
3	349b	1491a	1546a	1292ab	1127a
6	209c	1330ab	1365a	1152ab	1262a
9	21d	710c	1746a	1418a	1211a
12	26d	953bc	1411a	949b	1172a
Developmental stage[b]					
0	1.00a	1.02a	1.25a	1.54a	2.32a
3	1.00a	1.03a	1.16b	1.54a	1.83b
6	1.00a	1.00a	1.07c	1.41ab	1.46bc
9	1.00a	1.01a	1.01c	1.04c	1.21c
12	1.00a	1.00a	1.02c	1.18bc	1.50bc
Stems in bud stage (%)					
0		2.4a	20.0a	45.6ab	26.4ab
3		3.2a	16.0a	51.2a	36.8ab
6		0.8a	5.6b	34.4abc	28.0ab
9		0a	0.8b	4.0c	19.2a
12		0a	1.6b	18.4bc	41.6b

[a]Means within columns followed by the same letter are not significantly different (p = .05), Duncan's Multiple Range Test.

[b]1 = vegetative, 2 = bud, and 3 = flower.

Table 36 (continued)

Larvae per 0.1 m^2	Days after cutting[a]				
	7	14	21	28	35
Stems in flower stage (%)					
0		0	2.4a	6.4a	52.8a
3		0	0b	1.6ab	23.2b
6		0	0.8ab	3.2ab	14.4bc
9		0	0b	0b	0.8c
12		0	0b	0b	4.0c
Leaves per stem					
0		10.85a	16.50a	25.90a	51.37a
3		10.89a	17.63a	24.91a	42.09b
6		8.18a	13.24a	19.76ab	32.28c
9		5.01b	9.54b	14.28b	25.66c
12		4.82b	9.25b	16.16b	27.54c
Leaf area index (m^2/m^2)					
0		1.50a	1.73a	2.24a	3.51a
3		0.97b	1.54a	2.10ab	2.77ab
6		0.50c	0.86b	1.62ab	2.39b
9		0.14d	0.76b	1.60b	3.00ab
12		0.21d	0.78b	1.65ab	2.97ab
Dry weight (mg) per leaf					
0		9.47a	9.19a	6.34ab	4.26a
3		8.36a	8.07ab	6.29ab	4.58a
6		5.92b	6.07b	5.79a	4.85a
9		4.36c	6.45ab	6.15ab	5.68b
12		5.14bc	6.40ab	6.86b	5.73b
Area (cm^2) per leaf					
0		1.92a	1.49a	1.28ab	1.00a
3		1.47b	1.32a	1.31b	1.09a
6		0.88c	0.91b	1.10a	1.04a
9		0.52d	1.05b	1.41bc	1.53b
12		0.64cd	0.95b	1.59c	1.65b

Table 36 (continued)

Larvae per 0.1 m^2	Days after cutting[a]				
	7	14	21	28	35
Specific leaf weight (mg/cm^2)					
0		5.05a	6.13a	4.99a	4.24ab
3		5.70a	6.35a	4.83ab	4.22ab
6		7.56b	6.69a	5.28a	4.66a
9		8.17b	6.48a	4.41b	3.74bc
12		8.08b	6.81a	4.38b	3.48c
Leaf weight ratio (gm/gm)					
0		0.54a	0.50ab	0.50a	0.43a
3		0.56a	0.49a	0.50a	0.46ab
6		0.55a	0.56b	0.52a	0.50bc
9		0.59a	0.54ab	0.54a	0.51c
12		0.61a	0.56ab	0.51a	0.48bc
Leaf area ratio (cm^2/g)					
0		107.6a	85.8a	100.0a	108.9a
3		97.7a	82.8a	103.3a	109.2a
6		78.1b	85.3a	99.4a	107.7a
9		73.7b	87.1a	122.5b	140.4b
12		78.2b	89.4a	119.2b	136.4b
Yield (kg/ha)					
0		1393a	2071a	2228a	3200a
3		998b	1846a	2045a	2540b
6		592c	1010b	1654ab	2201b
9		199d	851b	1313b	2093b
12		232d	860b	1412b	2194b
Leaf yield (kg/ha)					
0		745a	1016a	1105a	1377a
3		555b	907a	994ab	1167ab
6		330c	567b	854bc	1093b
9		121d	451b	700c	1079b
12		158d	481b	727c	1021b

Table 36 (continued)

Larvae per 0.1 m^2	Days after cutting[a]				
	7	14	21	28	35
Stem yield (kg/ha)					
0		648a	1055a	1123a	1823a
3		443b	939a	1051ab	1374b
6		262c	443b	800abc	1107b
9		78d	500b	613c	1014b
12		74d	379b	685bc	1173b
In vitro digestible dry matter (%)					
0		76.09ab	69.72a	64.27a	64.00a
3		76.55ab	70.58ab	64.24a	64.31a
6		76.97ab	72.76bc	64.99a	65.41ab
9		75.43b	73.87cd	65.99a	67.55b
12		78.04a	75.10d	66.31a	66.97b
Crude protein (%)					
0		28.52a	22.34a	21.72a	23.21a
3		29.27a	22.75ab	22.41a	24.92ab
6		30.97a	25.96b	27.81a	26.02b
9		30.85a	30.02c	25.85b	26.40b
12		34.87b	30.26c	24.79b	26.71b

Table 37. Response of alfalfa regrowth to stubble injury by various densities of newly-molted, last-stage variegated cutworms in 1982

Larvae per 0.1 m^2	Days after cutting[a]							
	4	8	12	16	21	28	35	42
Stem height (cm)								
0		2.87a	7.05a	15.54a	21.75a	35.98a	47.85a	49.10a
1.5		2.29ab	5.12b	11.45b	17.23b	32.34ab	42.48b	46.02ab
3		2.05bc	3.94c	9.64b	16.82b	30.84b	40.10bc	47.29ab
6		1.11c	2.97c	6.40c	13.29b	28.64bc	40.07bc	43.79ab
9		0.68c	1.40d	2.66d	9.18c	25.82c	35.28c	42.11b
12		0d	0.25e	1.64d	4.78d	17.58d	29.43d	34.65c
Nodes per stem								
0		--	--	6.82a	7.69a	10.95a	13.83a	14.83a
1.5		--	--	6.28ab	7.26a	10.27ab	13.57ab	14.33a
3		--	--	5.74bc	7.02ab	10.23b	13.10b	14.38a
6		--	--	5.02c	6.44b	9.30c	12.22c	13.20b
9		--	--	3.59d	5.60c	8.70c	11.74c	12.61b
12		--	--	2.73d	4.45d	7.39d	10.60d	11.79c

[a]Means within columns followed by the same letter are not significantly (P = .05) different; Duncan's Multiple Range Test.

Table 37 (continued)

Larvae per 0.1 m^2	Days after cutting[a]							
	4	8	12	16	21	28	35	42
Leaves per stem								
0		2.6a	5.3a	8.4a	11.2a	26.0a	46.9a	63.6a
1.5		1.8b	4.0b	7.1ab	10.1a	22.3b	42.0ab	54.5ab
3		1.4b	3.6b	6.0bc	10.2a	20.8bc	39.8bc	53.6b
6		0.5c	2.4c	4.7c	8.3b	18.6cd	34.6cd	46.5bc
9		0.2c	0.7d	2.8d	6.9b	17.6d	29.3de	43.0c
12		0c	<0.1d	1.6d	5.1c	11.6e	25.7e	32.6d
Leaf area index (m^2/m^2)								
0		0.14a	0.99a	1.52a	1.94a	2.61a	3.82a	3.47ab
1.5		0.06b	0.43b	1.02b	1.27b	2.57a	3.21ab	3.08ab
3		0.03bc	0.25bc	0.91b	0.95bc	2.24ab	3.70a	3.15ab
6		0.015c	0.21cd	0.54c	0.65cd	1.93b	2.78bc	3.76a
9		0c	0.01d	0.12d	0.54d	1.81bc	2.64bc	2.99ab
12		0c	0d	0.03d	0.20e	1.23c	2.10c	2.47b
Leaf weight ratio (gm/gm)								
0		0.49a	0.60a	0.56ab	0.53a	0.47a	0.40a	0.38a
1.5		0.39ab	0.53ab	0.57a	0.54ab	0.48ab	0.42ab	0.41abc
3		0.28bc	0.51ab	0.62a	0.54ab	0.49abc	0.43b	0.39ab
6		0.19c	0.38bc	0.54ab	0.57b	0.51bc	0.44bc	0.42abc
9		0d	0.21cd	0.47b	0.57b	0.52c	0.46cd	0.42bc
12		-	0.07d	0.31c	0.57b	0.57d	0.48d	0.44c

Table 37 (continued)

Larvae per 0.1 m^2	Days after cutting[a]							
	4	8	12	16	21	28	35	42
Leaf area ratio (cm^2/gm)								
0		92.4a	140.0a	120.5a	100.0a	91.2a	86.7a	72.0a
1.5		67.4ab	110.2ab	120.2a	100.8a	96.3ab	91.0a	76.8a
3		43.0bc	105.9ab	125.4a	100.0a	96.9ab	96.9b	73.5a
6		32.2c	75.2bc	103.8a	100.2a	100.1b	100.7b	89.6b
9		13.2c	29.0cd	78.4b	104.3a	108.2c	109.8c	94.1b
12		--	2.7d	49.8c	105.8a	110.7c	110.3c	94.1d
Weight (mg)/leaf								
0		3.12a	6.96a	8.85a	10.15a	10.57ab	8.08a	7.22a
1.5		3.05a	5.22b	7.19b	8.17b	10.38ab	8.37ab	7.87a
3		2.40a	4.38b	7.02b	8.19b	11.21a	8.70ab	7.73a
6		1.49b	3.74b	5.03c	7.72bc	10.16ab	9.11b	7.64a
9		0c	2.12c	3.10d	6.39c	10.31ab	8.66ab	7.93a
12		0c	0.83c	1.96d	4.87d	9.35b	8.72ab	7.61a
Area $(cm)^2$/leaf								
0		0.58a	1.62a	1.91a	1.92a	2.07ab	1.76a	1.35a
1.5		0.52a	1.08b	1.50b	1.52b	2.07ab	1.82a	1.47ab
3		0.36b	0.91bc	1.42b	1.52b	2.20a	1.95ab	1.45ab
6		0.25bc	0.69c	0.97c	1.36bc	2.01ab	2.10b	1.64c
9		0.17c	0.30d	0.53d	1.44cd	2.15a	2.06b	1.77c
12		0d	0.03d	0.31d	0.90d	1.82b	1.97ab	1.62bc

Table 37 (continued)

Larvae per 0.1 m^2	Days after cutting[a]							
	4	8	12	16	21	28	35	42
Specific leaf weight (mg/cm^2)								
0		5.36ab	4.30a	4.65a	5.29a	5.13a	4.61a	5.34a
1.5		6.00ab	4.86a	4.76a	5.38a	5.02a	4.61a	5.40a
3		6.98a	4.84a	4.97a	5.40a	5.11a	4.46ab	5.33a
6		4.20a	6.40a	5.40ab	5.73a	5.09a	4.35ab	4.66b
9		--	5.49a	6.06b	5.57a	4.79a	4.22b	4.52b
12		--	6.25a	6.08b	5.59a	5.14a	4.42ab	4.73b
Yield (kg/ha)								
0		100a	469a	1075a	1516a	2863a	4403a	4805a
1.5		57b	260b	710b	1011b	2667ab	3536ab	4037ab
3		40b	156c	490c	907bc	2210bc	3828a	4322ab
6		13c	123c	324c	652cd	1918c	2824bc	4180ab
9		3c	20d	98d	545d	1687d	2398c	3230bc
12		0c	1d	32d	186e	1116d	1926c	2594c
Leaf yield (kg/ha)								
0		51a	187a	473a	713a	1521a	2654a	2982a
1.5		34b	121b	303b	467b	1384ab	2062b	2393ab
3		27b	76c	177c	418bc	1124bc	2187ab	2641ac
6		8c	60c	140c	286cd	958c	1605bc	2440ab
9		3c	15d	51d	235d	820c	1290cd	1860bc
12		0c	1d	20d	79e	483d	996d	1451c

Table 37 (continued)

Larvae per 0.1 m^2	Days after cutting[a]							
	4	8	12	16	21	28	35	42
Stem yield (kg/ha)								
0		49a	282a	602a	804a	1342a	1749a	1823a
1.5		23b	139b	407b	545b	1284a	1474ab	1654ab
3		13bc	80c	313bc	488bc	1086ab	1642a	1681ab
6		5cd	63c	184c	366bc	960b	1220bc	1740ab
9		0d	5d	48d	310c	866bc	1108c	1370bc
12		0d	<1d	12d	107d	633c	930c	1153c
Stem density (No./m^2)								
0	183a	908a	1154a	1208a	1015a	954a	945a	705a
1.5	109b	618b	993ab	1176a	885b	947a	845a	706a
3	101b	495b	752bc	1077ab	833bc	806a	886a	670a
6	48c	235c	615c	931bc	721c	803a	788a	708a
9	40c	118c	254d	749c	799bc	778a	822a	607a
12	15c	46c	115d	449d	543d	803d	828a	634a
In vitro digestible dry matter (%)								
0	--	--	--	--	70.11a	65.40a	64.46ab	61.99ab
1.5	--	--	--	--	72.66bc	67.29ab	63.82a	61.72ab
3	--	--	--	--	71.81ab	66.99ab	65.72ab	60.39a
6	--	--	--	--	74.83c	69.86b	66.73bc	63.22b
9	--	--	--	--	75.02c	69.80b	69.54d	61.97ab
12	--	--	--	--	78.42d	73.46c	68.99cd	65.37c

Table 37 (continued)

Larvae per 0.1 m^2	Days after cutting[a]							
	4	8	12	16	21	28	35	42
Crude protein (%)								
0	--	--	--	--	28.23a	22.95a	20.45a	19.26a
1.5	--	--	--	--	31.96b	23.33a	21.22a	19.52a
3	--	--	--	--	31.64b	23.65a	20.60a	19.35a
6	--	--	--	--	35.55c	24.35ab	22.41b	20.34a
9	--	--	--	--	36.69cd	25.49b	23.44b	20.26a
12	--	--	--	--	38.61d	28.56c	23.44b	21.69b
Developmental stage[b,c]								
0					1.00	1.17a	1.83a	2.45a
1.5					1.00	1.03b	1.70ab	2.16b
3					1.00	1.06b	1.64ab	2.10bc
6					1.00	1.01b	1.55b	1.90c
9					1.00	1.01b	1.13c	1.66d
12					1.00	1.00b	1.10c	1.47d

[b] All stems were vegetative up to day 21.

[c] 1 = vegetative, 2 = bud, and 3 = flower.

Table 37 (continued)

Larvae per 0.1 m^2	Days after cutting[a]							
	4	8	12	16	21	28	35	42
% Stems in bud stage								
0					100	16.8a	80.0a	40.8a
1.5					100	3.2b	66.4ab	66.4b
3					100	5.6b	62.4ab	60.8b
6					100	0.8b	53.6b	71.2b
9					100	0.8b	12.8c	60.0b
12					100	0b	9.6c	45.6a
% of stems on flower stage								
0					0	0	1.6a	52.0a
1.5					0	0	1.6a	24.8b
3					0	0	0.8a	24.8b
6					0	0	0.8a	9.6c
9					0	0	0a	2.4c
12					0	0	0a	0.8c

Table 38. Response of alfalfa regrowth to stubble injury by various densities of newly-molted, last-stage variegated cutworms in 1983

Larvae per 0.1 m^2	Days after cutting[a]				
	7	14	21	28	35
Developmental stage					
0	1.0	1.03a	1.30a	1.99a	2.92a
1.5	1.0	1.02ab	1.20a	1.81b	2.90a
3	1.0	1.01ab	1.18a	1.94a	2.89a
6	1.0	1.00b	1.03b	1.63c	2.69b
9	1.0	1.00b	1.00b	1.56c	2.43c
Stems in bud stage (%)					
0	0	3.0a	30.0a	83.0a	8.0a
1.5	0	2.0ab	20.0a	73.0abc	8.0a
3	0	1.0ab	18.0a	76.0ab	9.0a
6	0	0b	3.0b	59.0bc	29.0b
9	0	0b	0b	56.0c	43.0b
Stems in flower stage (%)					
0	0	0	0	8.0a	92.0a
1.5	0	0	0	4.0a	91.0a
3	0	0	0	9.0a	90.0a
6	0	0	0	2.0a	70.0b
9	0	0	0	0a	50.0c
Stem height (cm)					
0	7.52a	27.66a	41.64a	57.26a	71.92a
1.5	5.90b	25.36ab	40.69a	55.34a	71.34a
3	4.00c	24.07b	38.75a	54.31ab	69.18ab
6	1.82d	14.33c	29.19b	50.07bc	67.11ab
9	0.25e	8.75d	25.11c	45.84c	65.93b
Nodes per stem					
0	4.86a	7.13a	9.86a	12.57a	14.96a
1.5	4.41a	6.96a	9.74a	12.32a	14.83a
3	3.65b	6.58a	9.37a	12.03a	14.54a
6	2.01c	5.22b	7.73b	10.68b	13.23b
9	0.33d	4.33c	7.04c	9.77c	12.48c

[a]Means within columns followed by the same letter are not significantly (P = .05) different; Duncan's Multiple Range Test.

Table 38 (continued)

Larvae per 0.1 m^2	Days after cutting[a]				
	7	14	21	28	35
Leaves per stem					
0	4.27a	10.27a	19.28a	47.75a	70.70a
1.5	3.60b	9.65a	18.32a	40.29b	65.66ab
3	2.95c	9.78a	19.12a	39.67b	67.93ab
6	0.96d	6.23b	12.05b	30.08c	58.67b
9	0.02e	4.87b	10.01c	24.42c	46.54c
Leaf area index (m^2/m^2)					
0	.338a	1.83a	2.21a	2.98a	3.52a
1.5	.205b	1.53a	2.21a	2.62ab	3.49a
3	.126c	1.49a	2.12a	2.40b	3.68a
6	.010d	.80b	1.27b	1.85c	3.15a
9	<.0001d	.44b	1.04b	1.71c	3.22a
Leaf weight ratio (gm/gm)					
0	0.53a	0.47a	0.41a	0.39ab	0.29a
1.5	0.51a	0.51ab	0.41a	0.37a	0.31a
3	0.53a	0.49a	0.43a	0.39ab	0.31a
6	0.31b	0.55b	0.47b	0.39ab	0.34b
9	--	0.59c	0.49b	0.41b	0.34b
Leaf area ratio (cm^2/gm)					
0	98.1a	135.8a	89.8a	74.5a	66.3a
1.5	88.7a	140.2ab	97.8b	81.2ab	77.2b
3	89.0a	149.2b	101.8bc	81.3ab	71.7ab
6	49.1b	147.7b	104.8c	80.1ab	78.8b
9	--	149.9b	112.7d	90.6b	95.3c
Dry weight (mg) per leaf					
0	7.17a	11.52a	11.67a	9.74ab	6.98a
1.5	6.25b	11.27a	11.59a	9.10a	7.42ab
3	5.62b	10.15ab	10.90a	8.83a	7.29ab
6	3.90c	9.53bc	11.98a	10.12ab	8.41b
9	--	8.20c	11.52a	10.95b	8.49b

Table 38 (continued)

Larvae per 0.1 m^2	Days after cutting[a]				
	7	14	21	28	35
Area (cm^2) per leaf					
0	1.34a	3.31a	2.56a	1.88a	1.60a
1.5	1.09a	3.12ab	2.75a	2.00a	1.85a
3	0.94a	3.09ab	2.57a	1.85a	1.68a
6	0.78a	2.59bc	2.67a	2.07ab	1.98ab
9	--	2.09c	2.64a	2.42b	2.38b
Specific leaf weight (mg/cm^2)					
0	5.39a	3.49ab	4.55a	5.20a	4.38a
1.5	5.74a	3.62abc	4.24b	4.60a	4.03ab
3	5.97a	3.31a	4.24b	4.77ab	4.33a
6	7.72a	3.73bc	4.49ab	4.92ab	4.28a
9		3.95c	4.37ab	4.53b	3.58b
Yield (kg/ha)					
0	360a	1406a	2567a	4175a	5070a
1.5	238b	1141ab	2363ab	3408b	4790a
3	148c	1040b	2179b	3112b	5130a
6	20d	567c	1275c	2418c	4227b
9	7d	309c	971d	2004c	3913c
Leaf yield (kg/ha)					
0	189a	665a	1047a	1618a	1610ab
1.5	121b	577ab	976a	1260b	1466ab
3	79c	510b	941a	1202b	1664a
6	6d	305c	599b	949c	1410bc
9	<1d	182c	478c	813c	1193c
Stem yield (kg/ha)					
0	171a	741a	1519a	2557a	3952a
1.5	117b	564b	1388ab	2147b	3239ab
3	70c	530b	1238b	1910b	3697bc
6	13d	262c	676c	1469c	2806cd
9	1d	127c	493d	1191c	2335d

Table 38 (continued)

Larvae per 0.1 m^2	Days after cutting[a]				
	7	14	21	28	35
Stems per m^2					
0	879a	793a	662a	495a	458ab
1.5	756ab	750ab	650a	487a	428ab
3	676b	721ab	636a	483a	474a
6	254c	710ab	581a	443a	406b
9	76d	646b	590a	431a	427ab
In vitro digestible dry matter (%)					
0	--	--	68.01a	64.03a	58.00ab
1.5	--	--	68.94ab	64.23a	59.96bc
3	--	--	66.51a	62.64a	57.03a
6	--	--	71.73bc	64.66a	61.10c
9	--	--	75.15c	64.91a	61.10c
Crude protein (%)					
0	--	--	21.67a	20.23b	17.42a
1.5	--	--	21.49a	18.82a	18.67a
3	--	--	23.66a	20.79bc	18.03a
6	--	--	26.09b	21.90cd	18.72a
9	--	--	29.44c	22.46d	19.04a